THE UNIVERSITY OF ALBERTA

OPTIMUM FIELD MACHINERY SIZES
FOR
ALBERTA FARMS

by

© DONALD GORDON RUSSELL

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF AGRICULTURAL ENGINEERING

EDMONTON, ALBERTA

SPRING, 1969

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Optimum Field Machinery Sizes for Alberta Farms" submitted by Donald Gordon Russell in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

Optimum field machinery sizes are those sizes which will allow the farm operator to maximize his economic returns and are not necessarily the sizes which will minimize the cost of machinery. For this reason, optimum machinery sizes must be determined in relation to the total farm operation. The objectives of this thesis then are as follows: firstly, to determine the optimum size of field machinery for farms in Alberta and to compare these sizes with those already on the farm; secondly, to determine the optimum time period and minimum cost per acre for combining as an aid in satisfying the first objective; and thirdly, to determine the sensitivity of the total farm operation to deviations from the optimum sizes.

The method used to determine optimum machinery sizes was to solve mathematical programs of whole farm operations which included the sizing of field machinery. To determine the optimum time period and minimum cost per acre for combining, fixed and penalty costs of completing harvest in different time periods were assessed. The average penalty was assessed by simulating a thousand years of harvesting using the Monte-Carlo simulated sampling technique and a weather history. To determine the sensitivity of the total farm operation to deviations from the optimum, the mathematical programs were resolved for varying periods of available time to complete field work. This would in effect vary machinery sizes or machinery costs.

The results showed that machinery can be sized in relation to the total farm program and that a higher economic return may be expected by sizing machinery in this way than by selecting a program without considering machinery. Average annual machinery fixed costs are about $4.50 per acre or a little more than 17% of net income. Machinery costs are significant in a farmer's budget but not critical. A 10% oversizing of machinery will only decrease annual net income by a little more than 1.4%.

The optimum time for completing combining is 10 to 14 days regardless of acreage. The combine should be sized to complete harvesting in that time. The fixed and penalty (due to weather damage) combining costs per acre for a wheat farm at Edmonton are about $4.30 per acre. Purchasing a combine which will complete harvest quickly is probably valuable insurance because a large percentage of the time there will be no penalty at all, and if there is a penalty it will be smaller than the penalty for completing harvest more slowly.

Some farm operations seemed to be more sensitive to changes in machinery sizes or costs than others. In general, as machinery sizes or costs increase there is a shift away from cropping activities and toward animal activities. Purchasing field machinery larger than the optimum will decrease gross margin at a predictable rate. However, purchasing field machinery smaller than the calculated optimum may or may not decrease gross margin, depending on the ability of the farm operator to adjust his cropping program in the years where there are long periods of adverse weather.

ACKNOWLEDGEMENT

The competent guidance and assistance given by Dr. F.V. MacHardy is gratefully appreciated. Without this assistance the research for this thesis could not have been completed as presented. Dr. MacHardy's help in the presentation and organization of the manuscript made the task much more rewarding.

The help of Mr. P.L. Rutledge and Mr. W.E. Coates in writing computer programs is appreciated. Also, the assistance given by many of the staff of the Computing Science Department is acknowledged.

The many hours spent by Miss Louise Gadwa in typing the manuscript are gratefully appreciated. Typing this thesis with so many tables and graphs was a formidable task.

The published works of Dr. F.V. MacHardy, Mr. A.W. Anderson, and Mr. P.L. Rutledge which are referred to so frequently in the text and are used as a basis for this research are also acknowledged.

The information offered so readily when interviewing the district agriculturists and machinery salesmen made the assembling of the necessary data much easier. Their help as well as the help of many not mentioned is acknowledged.

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

G1. EDMONTON (STATION NUMBERS 2195-2208) - PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

G2. VERMILION (STATION NUMBER 6800) - PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

G3. CALGARY (STATION NUMBER 1080-1100) - PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

G4. LETHBRIDGE (STATION NUMBERS 3880-3890) - PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

G5. MEDICINE HAT (STATION NUMBER 4480) - PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

G6. BEAVERLODGE (STATION NUMBER 560) - PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

G7. FAIRVIEW (STATION NUMBER 2520) - PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

G8. EDMONTON (STATION NUMBERS 2195-2208) - PROBABILITY OF A WORK DAY ON SANDY SOILS

G9. VERMILION (STATION NUMBER 6800) - PROBABILITY OF A WORK DAY ON SANDY SOILS

G10. CALGARY (STATION NUMBERS 1080-1100) - PROBABILITY OF A WORK DAY ON SANDY SOILS

G11. LETHBRIDGE (STATION NUMBERS 3880-3890) - PROBABILITY OF A WORK DAY ON SANDY SOILS

G12. MEDICINE HAT (STATION NUMBER 4480) - PROBABILITY OF A WORK DAY ON SANDY SOILS

G13. BEAVERLODGE (STATION NUMBER 560) - PROBABILITY OF A WORK DAY ON SANDY SOILS

G14. FAIRVIEW (STATION NUMBER 2520) - PROBABILITY OF A WORK DAY ON SANDY SOILS

1. INTRODUCTION AND OBJECTIVES

In recent years machinery has replaced much of the labour on farms in the west. Machinery is expensive and because of the limitations on the crop growing season in Alberta, it is only used for very short periods of time. Therefore, the necessity arises for a farmer to have large machinery to complete his field work. Since the machinery inventory is large and expensive, the question arises as to whether or not the farm operator has machinery that is sized to make optimum use of his resources and maximize his economic returns.

The machinery itself does not return anything but supplies a means by which a farm operator may grow crops which will hopefully yield a return. For this reason field machinery may be looked on as a cost associated with growing crops. If limited, additional machinery may be considered as providing benefit. The decision to grow crops should not be made without considering the machinery necessary to seed and harvest the crop.

The principal objective, then, was to determine the optimum size of machinery for farms in the Province of Alberta and compare these sizes with machinery presently on the farm. For this, it was necessary to assess grain harvesting costs where crop losses are incurred by adverse weather. The third objective was to assess the sensitivity of the total farm operation to changes in field machinery size (or conversely, to time available for field operations).

2. LITERATURE REVIEW

A number of authors have developed techniques and conducted research in the field relating to this thesis topic which will assist in this type of research.

MacHardy (12, 14) developed a technique using Lagrange multipliers to determine the optimum size of field machinery where several machines are used in sequence. He also showed how the method of Lagrange multipliers can be combined with linear programming in an iterative procedure so that machinery can be sized in relation to the whole farm plan. MacHardy (11) has also developed a method of calculating harvesting costs for weather dependent harvest operations where increasing penalties are incurred for a decreasing rate of harvest.

A more recent development by MacHardy (13) is the use of product terms with integer programming for the inclusion of sequence field operations and harvesting costs in separable programs where time is a resource which must be shared with other farm activities.

Rutledge (19) has conducted research relating weather and field tractability to determine the probability of obtaining work days for tillage operations in various parts of the Province of Alberta.

Donaldson (5) has developed a simulation model for assessing harvest machine capacity while allowing for weather risk. His

work was done in England.

Donaldson and Webster (6) have used a simulation approach to whole farm planning. The method uses random numbers to select and size farm enterprises within resource restrictions. Using a computer program, more than a thousand different farming programs are setup and the top twenty solutions are printed as solutions from which the farmer may choose.

Preston (18) has applied the shortest path method of analyzing network diagrams to consider alternative methods of irrigating land. A computer program is used to find the shortest path which represents the least cost solution.

Link (10) has developed a mathematical model for predicting the effects of adverse weather and crop conditions on field machinery ststems. He applied his model to a hypothetical corn farm in Central Iowa.

Sowell and Link (22) have applied dynamic programming to the problem of machinery replacement with an application to cotton pickers.

Frisby and Bockhop (7) have used the mathematical model developed by Link (10) to determine when one system of machinery should be abandoned in favour of another as acreage increases. Their application was also for a corn crop.

Stapleton (23) shows how the computer can be used to analyze field machinery systems. His method uses timeliness functions to produce charts comparing different systems.

Hunt (9) presents a method of selecting field machinery using a series of equations relating economic and physical parameters of the problem. The method requiries some initial guess work and an iterative procedure to improve the solution if the initial guesses were wrong.

Although some development has taken place in supplying mathematical techniques for solving machinery sizing problems, very little application has taken place. What work has been done has usually just been enough to demonstrate the technique of the particular author in a particular local area.

3. SELECTION OF METHODOLOGY

3.1 Determination of the Optimum Machinery Sizes

As explained in the introduction, machinery must be sized in relation to the total farm operation. Choosing representative farms for a basis presented a problem since the statistical sources are not detailed enough to provide all the required data. However, Anderson's (2) thesis contained eleven linear programming models of farms in different parts of the Province of Alberta to which one could add machinery activities. These real case studies were chosen because they contained the necessary information and were distributed over the Province.

There were two methods available to add machinery activities to the linear programming models. One was to include product terms in a non-linear programming format called separable programming. The other was to use the Lagrange multiplier machinery sizing technique developed by MacHardy (14) and include the resulting solution in the linear program.

The use of product terms in linear and separable programming has the advantage that time may be included directly as a variable and thus a single procedure can be used. However, problems were encountered in using separable programming. Mathematically, separable programming will not guarantee a global minimum (or maximum). The method was attempted and no satisfactory way was found to make the solution move to a global minimum (or maximum),

and thus give least cost machinery sizes. The method was abandoned and the Lagrange multiplier - linear programming iterative procedure was used. This method consists of the following: first, solving the Lagrange multipliers using a) machine price data based on the expected final machinery sizes (in the case of non-linear fixed cost curves) and b) expected final acreages; and second, solving the linear program using the solution to the Lagrange multipliers as data. If the linear program solution was significantly different than the data used in the Lagrange multiplier calculations, the procedure was repeated using the linear programming solution as a basis for recalculating relative machine sizes.

This Lagrange multiplier - linear programming technique was used to size tillage and seeding machinery. Since most forage machinery comes in relatively fixed sizes these were included in the linear programs as fixed costs. Since the linear programming computer program (15) which was available did not have the facility for integer programming, separable programming was used to include a non-linear fixed cost curve. The method of including non-linear fixed cost curves is distinct from the product term technique and is explained in section 5.4. An explanation of the problem encountered in using product terms is also contained in section 5.4

3.2 Assessing Fixed and Penalty Costs of Harvesting

The methods explained in the above section are not satisfactory

for assessing harvesting costs because they do not take into account penalties incurred by adverse weather. However, the Monte-Carlo simulated sampling method has been used by MacHardy (11) and Donaldson (5) to assess penalties associated with delays in harvesting. A harvest cost simulation computer program was written by Coates (3) using MacHardy's (11) method, and data compiled in a 1968 student laboratory experiment. The method is explained in section 4 and the computer program is given in appendix F. The results are a minimum fixed and penalty combining cost and an associated optimum combining time period. The swather may then be included in the program as a fixed cost in the same manner as the haying equipment and is based on the assumption that swathing will be done before the crop is ready to be combined or during the combining period but never competing with the combine for time.

3.3. Analyzing the Sensitivity of the Total Farm Operation to Machinery Size Changes

The approach chosen for the sensitivity analysis was to use the same eleven case studies that were used in determining the optimum machinery sizes along with the Lagrange multiplier - linear programming iterative method. The harvest cost simulation computer program had not been written and the separable programming part of the Linear and Separable Programming Computer Package (15) was not available when these programs were solved. For these reasons all of the field machines were included in the linear

program as ordinary variables. Machine sizes were varied by increasing available time and solving the program at various time levels. A more detailed explanation of the methods is given in section 6.1.

4. FIXED AND PENALTY COSTS OF HARVESTING

4.1 Methods Used in Assessing Harvest Penalties

MacHardy's (11) method of sizing farm machines for weather dependent operations was used in this analysis. The procedure employs simulated sampling coupled with a weather history, and criteria for determining the penalty costs associated with adverse weather. Penalties associated with various sizes of machinery (or conversely various time periods to complete harvest) on a given acreage are assessed. The penalties may then be added to the fixed cost of the appropriate sizes of machines to give a total fixed and penalty cost per acre for the various machine sizes or harvesting time periods. It should be noted that operating costs per acre for various machine sizes are relatively constant and that if fixed costs are linear with respect to capacity, the cost-time curve calculated will be independent of acreage.

A computer program (contained in appendix F) was written by Coates (3) and modified by the author to simulate a thousand years of wheat harvesting. Data for inclusion in the harvest simulation program was not available except for primary weather data. To make use of this data, assumptions had to be made about grade losses for various levels of adverse weather. Since gathering this information and organizing it into a usable form

would be a major undertaking, the author chose to use the information obtained from a class consensus (1968). Admittedly the method does not show scientific accuracy but is probably not too far wrong. In any case a sensitivity analysis was conducted to determine the effect on the results if the basic assumptions were inaccurate.

The use of the computer program allowed the author to relax the assumption that fixed costs are linear and recalculate the penalties for various sizes of fields without laborious hand calculation. Also an analysis of the sensitivity of the cost-time curve to the good and bad (work and non-work) day probability functions could be conducted. A discussion of the methods and results is contained in the following sections.

Table 1 shows the number of days in a harvesting break for a given rainfall and drying conditions.

TABLE 1. WEATHER CRITERIA* FOR DETERMINING THE NUMBER OF DAYS DELAY IN HARVESTING

	Wind Velocity					
	< 10 M.P.H.		10-20 M.P.H.		> 20 M.P.H.	
Relative humidity	≤ 75%	> 75%	≤ 75%	> 75%	< 75%	> 75%
Rainfall (inches)	Days Delay					
0.05 - .15	1	1.5	.5	1	.5	1
.15 - .35	2	3	1	2	1	2
.35 - .75	3	4.5	2	3	2	3
> .75	4	6	3	5	3	4

* Established by a consensus of a class of thirty students (1968)

TABLE 2. GRADE OF GRAIN* AFTER ADVERSE WEATHER

Total days delayed	Adverse Weather Period 1	2	3	4	5	6	7
1	2	2	2	2	2	3	3
2	2	2	3	3	4	4	4
3	2	2	3	4	4	5	5
4	2	3	4	5	5	7	7
5	2	3	5	6	6	7	7
6	2	4	5	7	7	7	7
7	3	4	6	7	7	7	7
8	3	4	6	7	7	7	7
9	3	5	7	7	7	7	7
10	3	5	7	7	7	7	7
11	3	6	7	7	7	7	7
12	3	6	7	7	7	7	7
13	3	6	7	7	7	7	7
14	3	6	7	7	7	7	7
15	4	7	7	7	7	7	7
16	4	7	7	7	7	7	7
17	4	7	7	7	7	7	7
18	4	7	7	7	7	7	7
19	5	7	7	7	7	7	7

* Established by a consensus of a class of thirty students (1968)

Cumulative frequency distributions for work and non-work periods were drawn by the class using the weather record for Edmonton from 1950 to 1960.

Figure 1 shows these graphs.

Then a random number table was used to determine whether or not the season would start on a good or bad day. The table was then used in conjunction with figure 1 to pick the consecutive

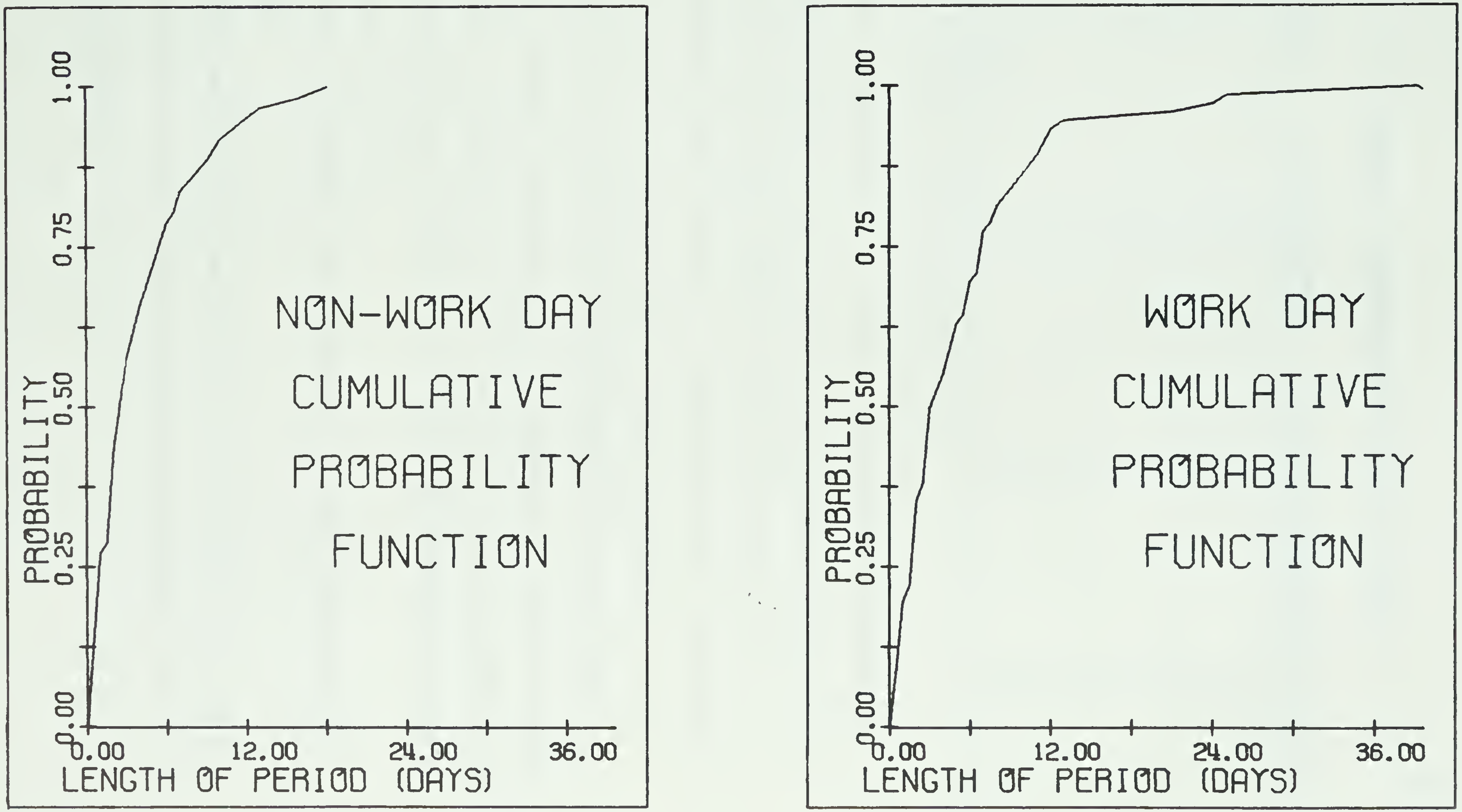


Figure 1. Cumulative probability functions for non-work and work periods measured in days.

TABLE 3. PENALTIES FOR LOSS OF GRADE

Grade	Total payment ($)	Penalty ($ per bu.)	($ per acre*)
1	1.82	-	-
2	1.79	0.03	.90
3	1.72	.07	2.10
4	1.66	.06	1.80
5	1.60	.06	1.80
6	1.58	.02	.60
7 (feed)	1.56	.02	.60

* Assuming: 30 bu/acre wheat crop

days of a work or non-work period. This was accomplished by picking a random number (between zero and one in decimal form) and using this random number as the Y axis value of the appropriate graph in figure 1. The intersection of this value and the curve yields the number of days on the X axis. This procedure was repeated alternating between the two graphs of figure 1 until the harvesting was completed or the season ended.

Table 2 specifies the loss in grade of wheat (assuming number one initially) for a given total number of bad days and a given bad weather period.

Table 3 specifies the dollar losses associated with grade losses.

Five combine sizes ranging from 2 to 17 ac/hr were used in this analysis. This assumes a yield of approximately one ton of grain per acre.

4.2 The Optimum Time Period and Minimum Cost Per Acre

Combine fixed costs were initially assumed to be linear at $280 per ton/hr capacity. Table 4 and figure 2 show the fixed and penalty costs for a 700 acre field for various harvesting time periods (or machine sizes).

From the graph we may observe that the optimum time for completing harvest is ten to fifteen days and that a combine sized to complete harvesting operations in that period will be the optimum size and cost roughly four dollars per acre for total penalty and fixed costs. As noted in section 4.1, this cost is independent of field and combine size since fixed costs are assumed linear. Figure 3 shows how much a farmer is penalized for buying a combine which is larger or smaller. The penalty for buying a larger machine is not nearly as great as one would suspect from observing figure 2 where the X axis is in time units. In fact the penalty increases at a greater rate when buying a combine too small as compared to buying one too large. Figure 3 is obviously dependent on the field and combine size but figure 2 is not.

The analysis may be made more accurate by recognizing that the fixed cost of combines is not quite linear. If this is the case, as the cost curve for combines in appendix C indicates, then the minimum fixed and penalty cost per acre will vary with field size and the harvest season will no longer be independent of acreage.

TABLE 4. FIXED AND PENALTY COSTS FOR VARIOUS COMBINE SIZES HARVESTING 700 ACRES

Combine size	Combine capacity (tons/hr)	Fixed cost ($/yr)	Total penalty ($/yr)	Total cost ($/yr)	Daily capacity at 10 hrs/day (ac/day)*	Days to complete harvest (days)	Fixed cost per acre ($/ac)	Penalty per acre ($/ac)	Total cost per acre ($/ac)
Smallest	2.0	560	3,436	3,996	20	35.0	.80	4.91	5.71
Small	3.5	1,120	1,950	3,070	35	20.0	1.60	2.79	4.39
Medium	6.5	1,820	974	2,794	65	10.8	2.60	1.39	3.99
Large	11.0	3,080	546	3,626	110	6.4	4.40	.78	5.18
Largest	17.0	4,760	364	5,124	170	4.1	6.80	.52	7.32

* Assuming one ton per acre

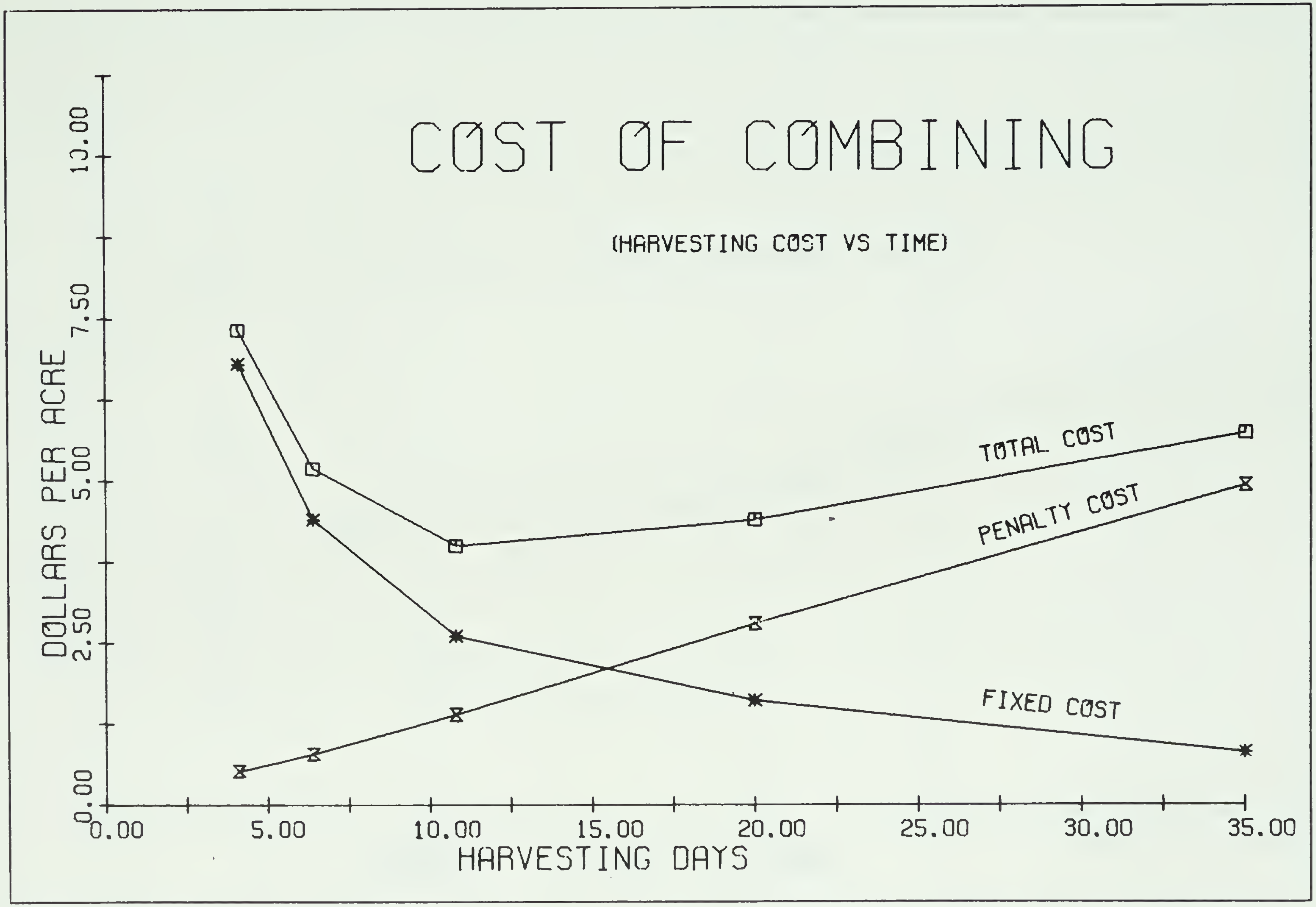


Figure 2. Fixed, penalty and total fixed plus penalty cost curves for completing harvest in different time periods.

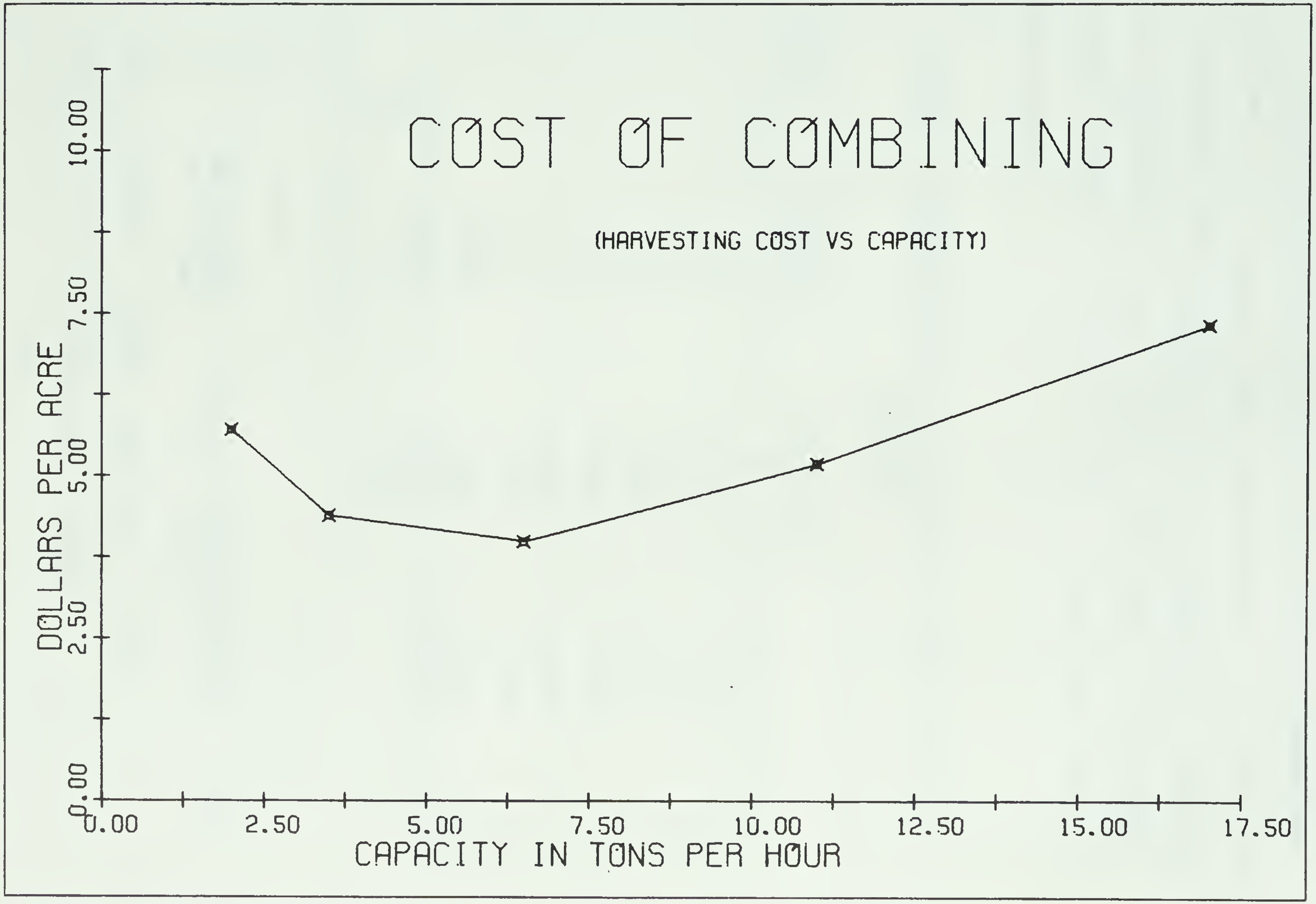


Figure 3. Total yearly fixed and penalty cost curve for harvesting 700 acres with different combine sizes.

To investigate this further, fixed costs were established by using a least-squares linear approximation to the combine data of appendix C and extrapolating to the larger sizes. The machine was considered to be paid for over seven years at 7% per annum simple interest on the unpaid balance. Tables 5 and 6 show the calculations.

TABLE 5. REGRESSION LINE CALCULATION FOR THE FIXED COST OF COMBINES

Combine number	Capacity * (ton/hr) X	Total cost ($) Y	XY	X^2
1	3.90	11,050	43,095	15.21
2	5.64	12,010	67,736	31.81
3	7.48	13,991	104,653	55.95
4	5.62	11,975	67,300	31.58
5	7.30	14,075	102,748	53.29
6	3.52	9,275	32,648	12.39
7	3.28	7,675	25,174	10.76
n = 7 Sum =	36.74	80,051	443,354	210.99
Mean =	5.25	11,436		

* Estimated using MacHardy's (12) formula

$$Y = a + bX$$

$$b = \frac{\Sigma XY - nMxMy}{\Sigma X^2 - n(Mx)^2} = \frac{433{,}354 - 7(5.25)(11{,}436)}{211 - 7(5.25)^2} = 1282$$

$$a = My - bMx = 11436 - 1282(5.25) = 4705$$

Combine cost = \$4705 + \$1282 (ton/hr)

TABLE 6. YEARLY PAYMENT PLUS INTEREST FOR VARYING COMBINE SIZES

Size	Capacity (ton/hr)	Purchase price ($)	Capital cost allowance*	Average yearly interest at 7%/annum ($)	Total yearly fixed cost ($)
Smallest	2.0	7269	1038	218	1256
Small	3.5	9192	1313	276	1589
Medium	6.5	13038	1863	391	2254
Large	11.0	18807	2687	564	3251
Largest	17.0	26499	3786	795	4518

* Assumes combine written off in seven years.

Computer runs were then made and tables and graphs drawn to show the changes in costs as the acreage changes. Six runs were made on field sizes ranging from 300 to 2300 acres in 400 acre increments. Table 7 shows the fixed and penalty costs for the different machines on the different acreages. Figure 4 shows the total cost curves.

TABLE 8. MINIMUM COST PER ACRE AND OPTIMUM TIME PERIOD FOR VARIOUS ACREAGES

Acres to be combined	Minimum cost/acre (dollars)	Time period for minimum cost (days)
300	6.20	10 - 15
700	4.50	10 - 15
1100	4.20	10 - 15
1500	4.01	10 - 15
1900	3.88	10 - 15
2300	3.82	10 - 15

TABLE 7. YEARLY FIXED AND PENALTY COSTS FOR VARIOUS ACREAGES AND COMBINE SIZES

Combine size	Fixed cost ($)	Penalty cost ($)	Total cost ($)	Daily capacity (ac/day)	Days to complete harvest	Fixed cost per acre ($)	Penalty per acre ($)	Total cost/ac ($)
	Acres = 300							
Smallest	1256	611	1867	20	15.0	4.19	2.04	6.22
Small	1589	332	1921	35	8.6	5.30	1.11	6.40
Medium	2254	186	2440	65	4.6	7.51	0.62	8.13
Large	3251	120	3371	110	2.7	10.84	0.40	11.24
Largest	4581	89	4670	170	1.8	15.27	0.30	15.57
	Acres = 700							
Smallest	1256	3436	4692	20	35.0	1.79	4.91	6.70
Small	1589	1950	3539	35	20.0	2.27	2.78	5.05
Medium	2254	974	3228	65	10.8	3.22	1.39	4.61
Large	3251	546	3797	110	6.4	4.64	0.78	5.42
Largest	4581	364	4945	170	4.1	6.54	0.52	7.06
	Acres = 1100							
Smallest	1256	7449	8705	20	55.0	1.14	6.77	7.91
Small	1589	4870	6459	35	31.4	1.44	4.43	5.87
Medium	2254	2583	4837	65	16.9	2.05	2.35	4.40
Large	3251	1415	4666	110	10.0	2.96	1.29	4.24
Largest	4581	876	5457	170	6.5	4.16	0.80	4.96

Continued . . .

TABLE 7. CONTINUED

Combine size	Fixed cost ($)	Penalty cost ($)	Total cost ($)	Daily capacity (ac/day)	Days to complete harvest	Fixed cost per acre ($)	Penalty per acre ($)	Total cost/ac ($)
	Acres = 1500							
Smallest	1256	11702	12958	20	75.0	0.84	7.80	8.64
Small	1589	8626	10215	35	42.8	1.06	5.75	6.81
Medium	2254	4950	7204	65	23.1	1.50	3.30	4.80
Large	3251	2768	6019	110	13.6	2.16	1.85	4.01
Largest	4581	1669	6250	170	8.8	3.05	1.11	4.16
	Acres = 1900							
Smallest	1256	15967	17223	20	95.0	0.66	8.40	9.06
Small	1589	12772	14361	35	54.3	0.84	6.72	7.56
Medium	2254	7860	10114	65	29.2	1.19	4.14	5.33
Large	3251	4564	7815	110	17.3	1.71	2.40	4.11
Largest	4581	2791	7372	170	11.2	2.41	1.47	3.88
	Acres = 2300							
Smallest	1256	20232	21488	20	115.0	0.55	8.80	9.35
Small	1589	17018	18607	35	65.6	0.69	7.40	8.09
Medium	2254	11327	13581	65	35.4	0.98	4.90	5.88
Large	3251	6794	10045	110	20.9	1.41	2.95	4.36
Largest	4581	4205	8786	170	13.5	1.99	1.83	3.82

Table 8 summarizes the results shown in figure 4.

Figure 5 shows the fixed and penalty cost curve for each combine size over varying acreages.

Note that non-linearities in the fixed cost of combines does not appreciably change the time period in which the minimum cost harvesting is to be completed. It is still about 14 operating days. The combine will then be sized according to the acreage. Also the combination of fixed and penalty costs is still about four dollars per acre. However, for acreages under 1000 acres the cost per acre does rise considerably as acreages decrease due to the "base" cost of a combine.

The program assumed that harvesting not completed within sixty days was completed in the following spring without any further penalty. Therefore, for the smaller machines on large acreages, the full sixty days were used. This means that the penalty on small machines for large acreages is not large enough. The error will have no affect on the above observations but should be kept in mind when interpreting the figures and tables.

4.3 Distribution of Penalties Associated with Various Machine Sizes

Another interesting observation which may be made is the distribution of penalties, or, in other words, the number of times that a penalty occurred of $0, $1000, $2000 and so on. The distributions of penalties for the various combine sizes on 1100 acres are shown in figure 6.

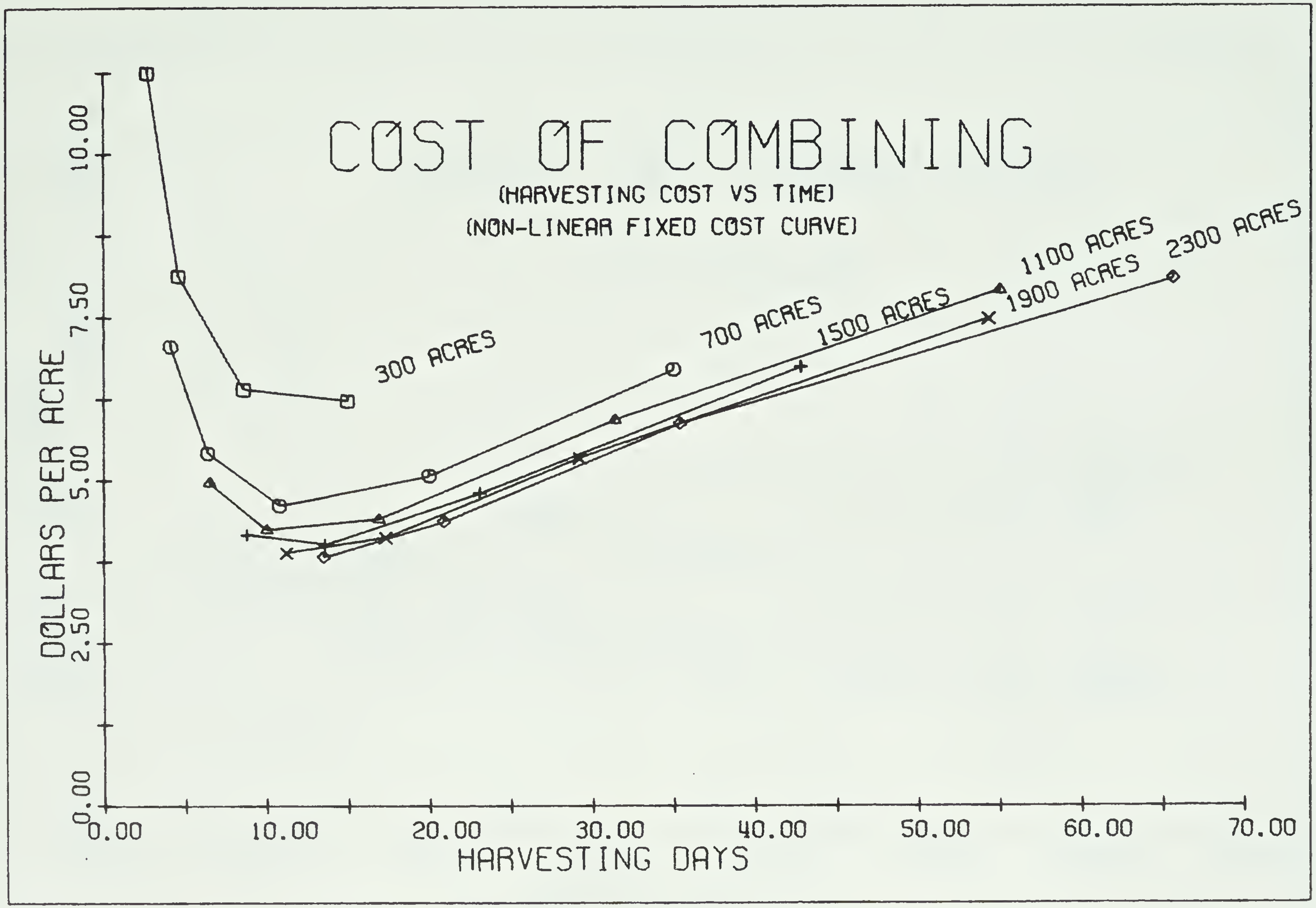


Figure 4. Total yearly fixed and penalty costs per acre for harvesting a gradient of acreages in varying time periods.

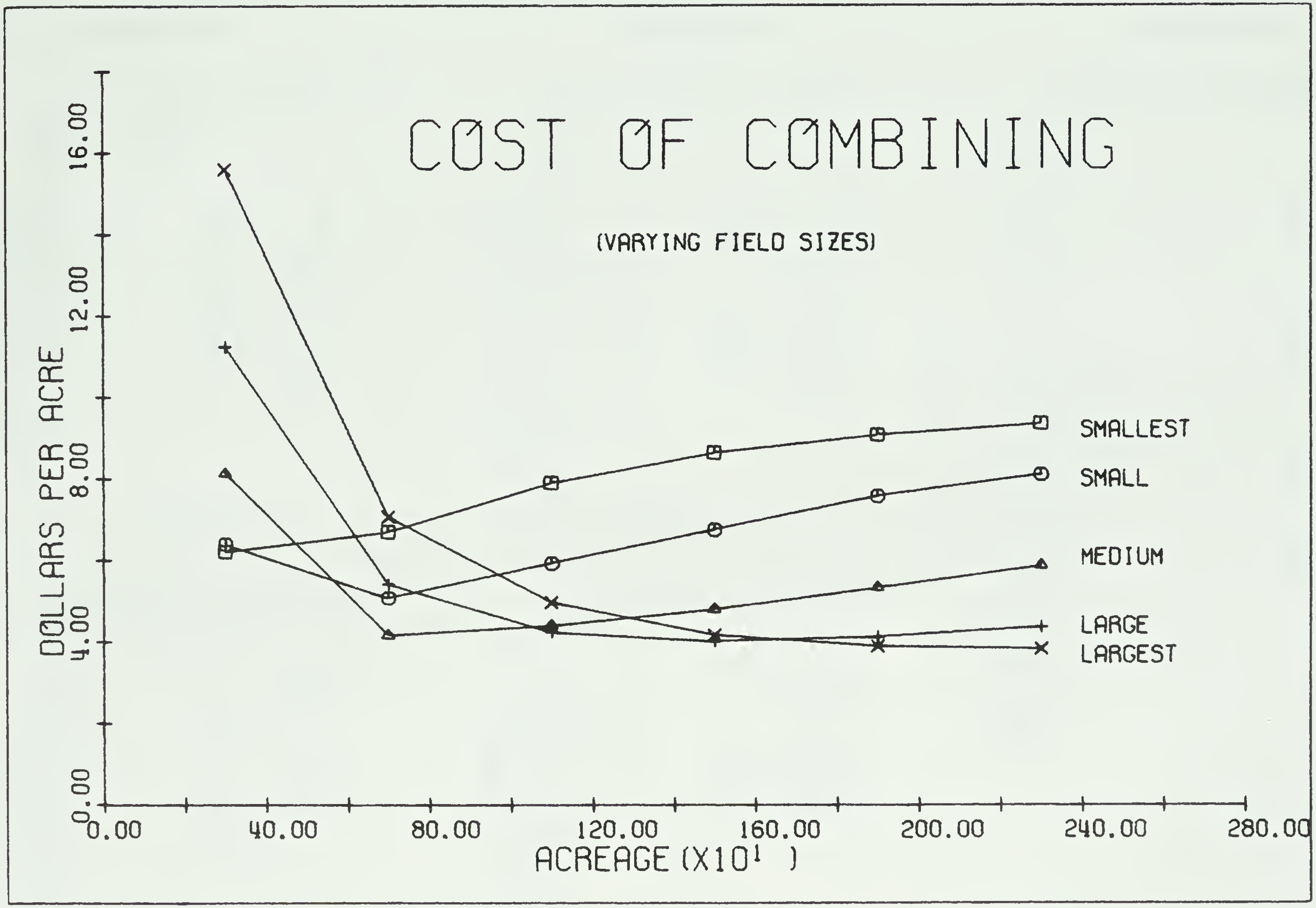


Figure 5. Total yearly fixed and penalty harvesting costs for various acreages with different combine sizes.

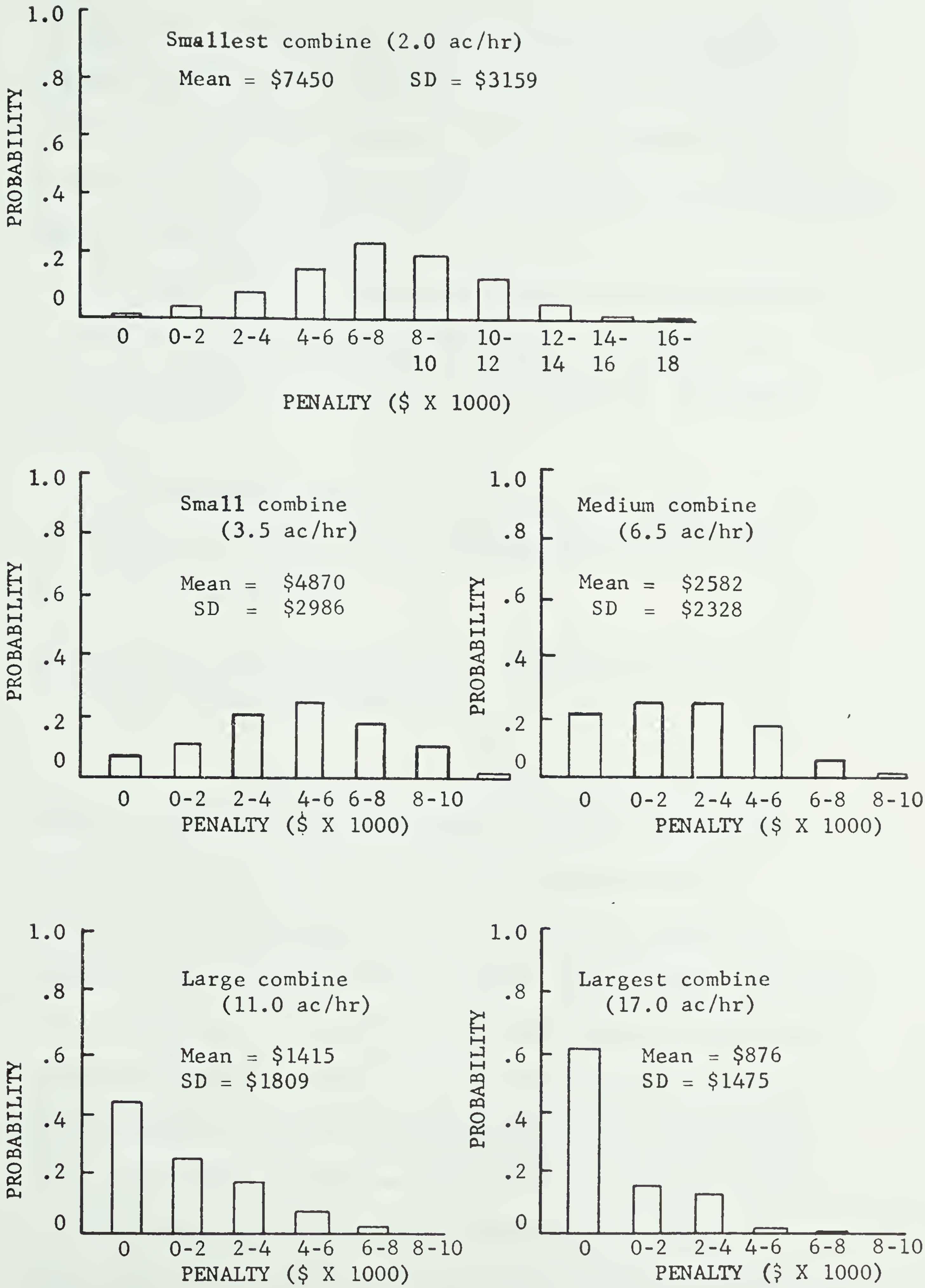


Figure 6. Distribution of penalties for varying combine sizes on 1100 acres.

Note that the larger the combine, the higher the percentage of years that there was a penalty of zero. Also the smaller the combine, the higher the standard deviation of penalties becomes (or the distribution widens), and the high point on the distribution comes at a higher penalty.

In other words, the larger the combine, the more predictable the penalty becomes, the smaller the penalty is likely to be (if there is any), and the chance of no penalty at all becomes greater.

The distribution of penalties for the other acreages were also obtained but they followed the same pattern as the ones given so are not included.

4.4 Sensitivity of the Optimum Time and Minimum Cost to the Weather Probability Functions

In this simulation model, the weather data used were for Edmonton. There was no way of obtaining weather probability functions for other parts of the Province without either laboriously working through a number of years of weather data by hand or by doing some extensive computer programming. Therefore, it was decided that an analysis of the sensitivity of the harvest simulation program to changes in the work day and non-work day functions would provide much information without a great deal of effort. The 1100 acre farm was chosen for the analysis and two runs were made; One with the work day probability function increased 10% and non-work day probability function decreased 10%,

TABLE 9. YEARLY FIXED AND PENALTY COSTS FOR VARIATIONS IN THE WORK AND NON-WORK DAY PROBABILITY FUNCTIONS

Combine size	Capacity (ac/day)	Days to complete harvest	Fixed cost ($)	Penalty cost ($)	Total cost ($)	Fixed cost per acre ($)	Penalty cost per acre	Total cost per acre ($)
	Good (Work) Day Function +10%				Bad (Non-Work) Day Function -10%			
Smallest	20	55.0	1256	6993	8249	1.14	6.36	7.40
Small	35	31.4	1589	4358	5947	1.44	3.96	5.40
Medium	65	16.9	2254	2204	4458	2.05	2.00	4.05
Large	110	10.0	3251	1188	4439	2.96	1.08	4.04
Largest	170	6.5	4581	743	5324	4.16	0.68	4.84
	Good (Work) Day Function -10%				Bad (Non-Work) Day Function +10%			
Smallest	20	55.0	1256	8598	9854	1.14	7.82	8.96
Small	35	31.4	1589	6269	7858	1.44	5.70	7.14
Medium	65	16.9	2254	3701	5955	2.05	3.36	5.41
Large	110	10.0	3251	2114	5365	2.96	1.92	4.88
Largest	170	6.5	4581	1297	5878	4.16	1.18	5.34

Field size = 1100 acres

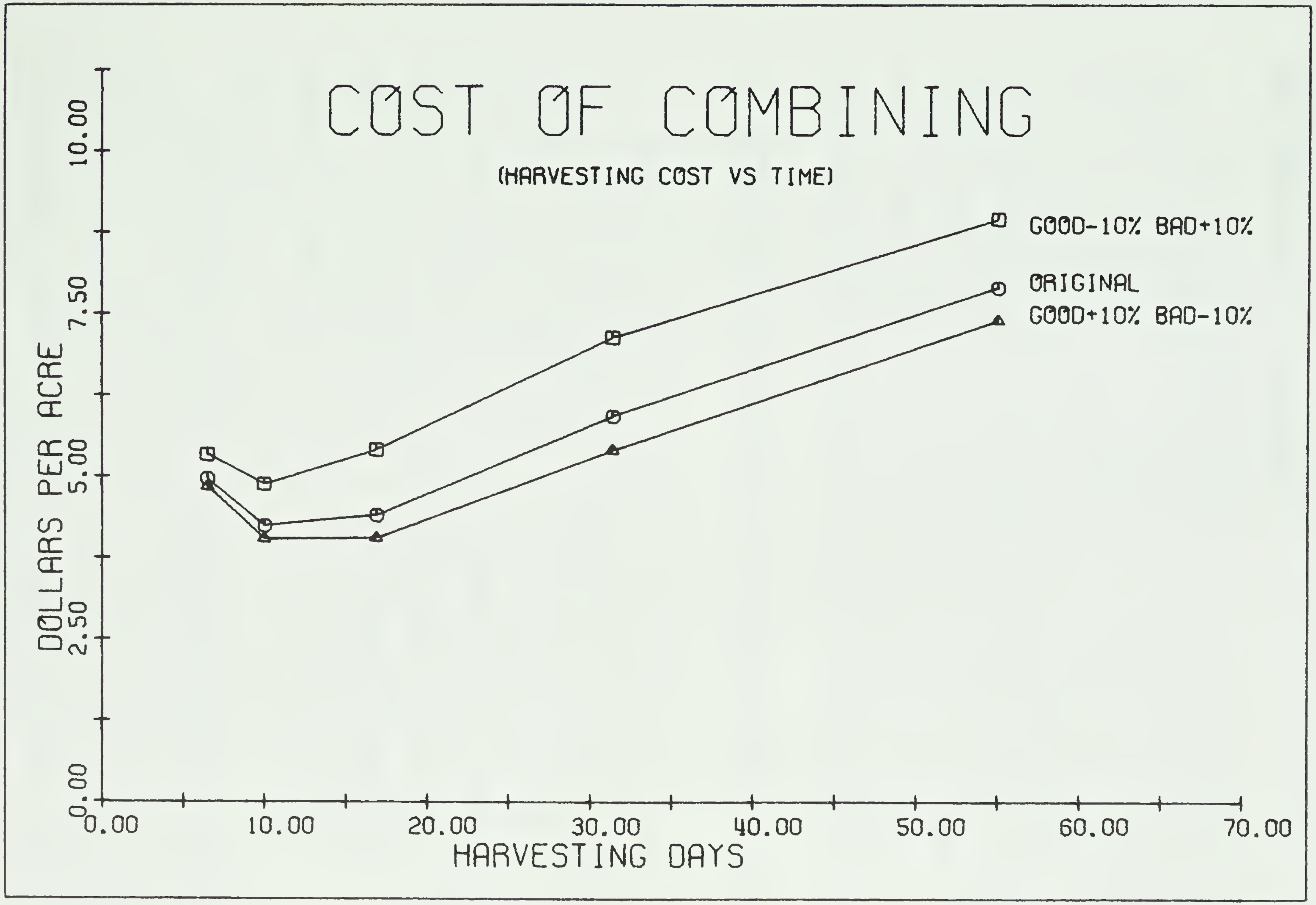


Figure 7. Total yearly fixed and penalty costs curves for variations in the work (good weather) and non-work (bad weather) functions.

and the other run with the opposite combination. The results are shown in table 9 and figure 7.

Note that the lowest cost per acre ranged from $4.00 - 4.60 and that the model does not seem to be very sensitive to changes in the work and non-work day probability functions. Also note that as the work day probability function increased and non-work day probability function decreased, the optimum time for harvesting increased and the optimum combine size decreased. The opposite results were obtained when the work day probability function was decreased and the non-work day probability function was increased.

4.5 Conclusions and Discussion of the Fixed and Penalty Costs of Harvesting

The minimum fixed and penalty cost is about $4.30 per acre and occurs when harvesting is completed in two weeks, regardless of acreage. The combine should be sized according to the acreage to be completed. Over a number of years there is a higher total cost per acre for buying a combine too small than buying one too large. In any one year there is a much greater probability of obtaining a penalty of zero with a large combine than with a small combine.

One assumption in this simulation model which may be questioned is that there are penalty costs incurred for having crops in the field when harvesting is stopped due to rain. The penalties used were for wheat and were estimated by student consensus. What penalties are incurred with other grain were not estimated.

Feed barley probably has a high loss from heads being beaten into the ground during a rain. Feed oats may have few losses associated with adverse weather.

Another assumption which may be questioned is that the combine is written off in seven years. In reality the combine will probably have considerable trade in value which will make the annual fixed cost curve of figure 2 seem unreasonably high. However, the curve is probably reasonably accurate because fixed costs include costs other than depreciation (eg. insurance).

It is obvious from figure 2 that as penalties increase the larger combines will become more favorable. As fixed costs increase the smaller combines will become more favorable.

It is also interesting to note that MacHardy's (13) method for including the total cost curve of figure 2 in a mathematical program will permit competition with all other activities for available capital and time. The farm business generates its own internal interest rate and, if capital is limiting, the internal interest rate can be much above bank rate. Under these circumstances the effective fixed costs associated with the combine would be high and would tend to favour a less costly (smaller) combine. This technique was not used in the mathematical programming because of the unavailability of integer programming.

5. THE OPTIMUM FIELD MACHINERY SIZES

5.1 Aquisition of Data and the Method of Analysis

To include machinery activities in Anderson's (2) case studies, the amount of time available for field crop operations, and the machine power requirements and fixed costs must be known.

For any field crop operation the amount of available time may be established by multiplying the average probability of obtaining a work day by the total number of days available for the operation. For this reason, district agriculturists in the localities of the case studies were interviewed and from information obtained in the interview, outside limits on field crop operations were established (see appendix A).

Rutledge's (19) research relating the weather and field tractability produced monthly probabilities for tillage and traction. However, since the seasons for field operations do not necessarily start and end with the months of the year, daily probabilities which could be summed over any period of time would be more accurate. Tables containing work and non-work days for seven stations in the Province of Alberta for as many years as weather data could be obtained (20-50 years depending on the station) were also produced by Rutledge (19). These tables were available at the University of Alberta on magnetic tape in computer card image form. Rutledge and the author wrote a computer program jointly to

calculate the probabilities on a daily basis. The probabilities for work days are contained in appendix G.

Estimates of machinery fixed costs per unit capacity were also required. This information was obtained by visiting two distributors of farm machinery in Edmonton, Alberta and collecting the retail price of the machines used in the mathematical programs.

The data were compiled and graphs relating cost and capacity were drawn. These are shown in appendix C.

The accuracy of the fixed cost data may be questioned since most farmers would probably pay less than the retail price. However, farmers may also obtain more "extras" on their machines than is included in the retail prices given. The method of "eying in" the lines relating cost and capacity may also be questioned. However, prices for different makes of the same type of machine and same capacity cover a range, and are not equivalent. Therefore, for general programming where the choice of machine make is not known, this general curve is satisfactory. For programming a case where personal preference is known a more accurate cost curve representation may be drawn.

Two sources of data were available for determining the horsepower requirements of field machinery. The American Society of Agricultural Engineers' Yearbook (1967)(17) gives estimates of draft for different machines from which horsepower requirements may be calculated. The Agricultural Machinery Administration (1) in Saskatchewan did some testing of field machinery to determine

their power requirements. Both these sources were used to determine machine power requirements. These calculations are shown in appendix B.

The solutions given by Anderson (2) were used as the first estimate of the cropping pattern that was likely to appear in the linear program solution. Season limits for crops in the particular area were obtained from appendix A and the number of work days could then be obtained by adding the work day probabilities (shown in appendix G) for the appropriate region and soil class.

The soil class categories used are those used by Rutledge (19) in determining field tractability and thus work day probabilities. They are "medium to heavy" and "sandy" soils. Upon observation of the soil survey maps (21), it was found that the predominant soils in the case studies would fall into the category of medium to heavy soils, rather than sandy soils. For this reason and also since the medium to heavy soil class has generally lower work day probabilities than the sandy soil class, the medium to heavy soil was chosen for all case studies. The weather station used was that suggested by the District Agriculturist of the area and recorded in appendix A.

Since the work day probabilities given in appendix G are based on ability to cultivate the soil and obtain sufficient tire traction, and have nothing to do with crop conditions they were used for determining seeding and summer fallow work periods only. The Lagrange multiplier - linear programming iterative

procedure (as described in section 3.1) was used to determine the optimum combination of tillage and seeding machinery. Harvesting costs for crops harvested with a combine were included at a flat rate of $4.60 per acre. The swather, forage harvesting, and haying machinery were included as annual fixed costs according to table C1 in appendix C. The method of including these fixed costs in mathematical programs is explained in section 5.4.

The following sections contain a summary of the land management techniques specified by Anderson (2), as well as the calculation of available time. Horsepower requirements and machinery costs were obtained from appendices B and C respectively.

The following sections also contain the results obtained by Anderson (2) called "solution 1" and the results obtained by the author called "solution 2". However, the two solutions are not directly comparable as they stand. Solution 1 is the solution obtained by Anderson (2), and includes no machinery fixed costs. Solution 2 is the solution of the mathematical programs set up by the author and includes all machinery costs. Also, since solution 2 is based on a one man operation for field work, cost adjustments for full time labour beyond a one man operation must be made. Solution 1 also needs cost adjustments since a number of case studies contain more than one man in their permanent labour force . Then comparable gross margins could be derived. The derived costs and gross margins are given at the bottom of each solution table.

The comparable gross margin in solution 1 is then the gross margin minus the annual fixed cost of all machinery on the farm (except the combine), minus the total fixed and penalty cost associated with the particular combine size, minus the cost of additional full time labour beyond one man. The cost calculations of the machinery on the farm includes only the types required by the solution. The sizes are those given by Anderson (2). The annual machinery fixed costs were obtained from the fixed cost curves and tables of appendix C and are based on a machine life of seven years. The depreciation rate was assumed to be linear. The total fixed and penalty cost of combining was obtained by calculating the number of days to complete harvesting from the acreages given in solution one and the combine capacity available on the farm. (The capacity was estimated using the combine makes given by Anderson (2) and MacHardy's (12) formula to calculate the capacity). Then, given the harvesting period, figure 1 was used to obtain the total fixed and penalty costs per acre which was then multiplied by the number of acres to be harvested. Labour costs for solution 1 were assessed at a flat rate of $500 per extra man for tillage and seeding, $400 per extra man for haying, and $280 per extra man for harvesting.

The comparable gross margin of solution two is the gross margin minus additional labour if a multi-man operation was required. Labour costs for additional men were obtained by assessing a cost of $20 per day per man for each work day in the tillage and seeding period, for 14 work days for grain harvesting,

and for 20 work days for hay harvesting. Only the operations which needed an extra man were included for calculating the cost of labour. It was assumed that if the livestock operation was large, one additonal man was required to look after the livestock.

The second table given with the results of each case study contains the machinery required for each solution for tillage and seeding operations, and grain harvesting. Since haying machinery sizes are relatively fixed, they are not listed in the table. The capacities for solution 1 were obtained by using the machinery sizes given by Anderson and the size-capacity relationships shown in appendix C. The capacities for solution 2 are those given in the solutions to the mathematical programs.

Available tractor horsepower was calculated by using 65% of the maximum available belt horsepower given in the Nebraska Tractor Tests (16) for the particular make and model. The factor of 65% was chosen because Domier (4) has suggested that 55-75% of maximum pto horsepower is usable drawbar horsepower when a tractor is pulling machinery in the field.

Combine sizes for method 2 were obtained by totalling the acreage to be combined and dividing by fourteen days.

5.2. Mathematical Program Data and Results for Eleven Case Studies

5.2.1 Case 1

Region: Vulcan - Arrowwood

Weather staion used: Calgary

Soil types: Medium to heavy

Tillage and seeding time (for wheat)

April 8 to May 21 = 25 work days at 10 hrs/day
= 250 hours

Tillage and seeding machinery in sequence: Chisel plow
One-way disker
Harrow

Grain harvesting machinery: Swather
Combine

Results: See tables 10 and 11.

Annual machinery costs for solution 1:

$3160 fixed cost for tractors, and tillage and seeding machinery

500 fixed cost for swather

8940 fixed and penalty costs of harvesting ($4.75/acre for 1881 acres)

Labour costs for solution 1:

$500 for seeding

280 for harvesting

Labour costs for solution 2:

$500 for seeding

280 for harvesting

780 for livestock

TABLE 10. COMPARISON OF SOLUTIONS: CASE 1

Activity	Solution 1	Solution 2
Gross margin ($)	56,000	49,522
Land purchase (ac)	1,000	1,000
Spring wheat on fallow (ac)	1,178	700
Flax on fallow (ac)	100	-
Durum what on fallow (ac)	603	-
Spring wheat (ac)	-	1,885
Fallow (ac)	703	700
Cover crop (ac)	703	492
Cow - calf	239	240
Winter calves	150	152
Machinery costs for solution 1 ($)	11,100	-
Labour costs for solution 1 ($)	780	-
Labour costs for solution 2 ($)	-	1,560
Comparable gross margin ($)	44,120	47,962

TABLE 11. MACHINERY REQUIRED FOR CASE 1 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable HP)	114	166
Chisel plow (ac/hr)	7	19
One-way disker (ac/hr)	7.5	30
Harrow (ac/hr)	11	106
Combine (ac/day)	75	185

5.2.2 Case 2

Region: Vulcan - Arrowwood

Weather station used: Calgary

Soil types: Medium to heavy

Tillage and seeding time (for wheat):

April 8 - May 21 = 25 work days 10 hrs/day
= 250 hours

Fallow: must be cultivated during seeding

Tillage and seeding machinery in sequence:

Chisel plow with rod weeder attachment
Press drill

Grain harvesting machinery: Swather
Combine

Results: See tables 12 and 13.

Annual machinery costs for solution 1:

\$2600 fixed costs for the tractors, and tillage and seeding machinery.

500 fixed cost for the swather

7920 fixed and penalty costs for harvesting (\$4.60/acre for 1720 acres)

Labour costs for solution 1:

\$1000 for seeding

560 for harvesting

Labour costs for solution 2:

\$780 for livestock

TABLE 12. COMPARISON OF SOLUTIONS: CASE 2

Activity	Solution 1	Solution 2
Gross margin ($)	55,600	46,180
Durum wheat on fallow (ac)	860	859
Spring wheat on stubble (ac)	860	-
Fallow (ac)	860	859
Barley on stubble (ac)	-	870
Cows - sell calves	180	200
Fatten calves	275	271
Machinery costs for solution 1 ($)	11,020	-
Labour costs for solution 1 ($)	1,560	-
Labour costs for solution 2 ($)	-	780
Comparable gross margin ($)	43,020	45,400

TABLE 13. MACHINERY REQUIRED FOR CASE 2 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable HP)	91	52
Chisel plow - rod weeder (ac/hr)	7.5	4.6
Press drill (ac/hr)	8.2	13.9
Combine (ac/day)	100*	61

* The farmer had two machines and the capacity of one had to be estimated.

5.2.3 Case 3

Region: Vulcan - Arrowwood

Weather station used: Calgary

Soil types: Medium to heavy

Tillage and seeding time (for flax):

April 8 - June 18 = 53 work days at 10 hrs/day
= 530 hours

Tillage and seeding machinery in sequence:

Chisel plow and rod weeder in tandem
Double disker and press drill in tendem

Grain harvesting machinery: Swather
Combine

Hay harvesting machinery: Mower
Rake
Baler

Results: See tables14 and 15.

Annual machinery costs for solution 1:

\$2480 fixed costs for the tractor, and tillage and seeding machinery

500 fixed cost for the swather

2700 fixed and penalty costs of harvesting (\$4.60 per acre for 586 acres)

Anderson (2) did not list a mower, rake and baler for this case so the cost of these machines was omitted in the calculation of the comparable gross margin for solution 1 even though it is included in the comparable gross margin for solution 2.

In this case the post-optimal information suggested that solution 2 would not change until the cost of the swather, mower, rake and baler was either ridiculously high or low. However, the total annual fixed cost of these machines had not entered the solution. The cost of the machines in solution 2 are \$.83 per acre for the swather, \$.33 per acre for the mower, \$.33 per acre for the rake and \$.55 per acre for the baler.

The total amount included in the solution was 98% of the total fixed cost for each of the swather, mower and rake and 49% for the baler. One may conclude that the swather, mower and rake are essentially paid for but the baler must be rented. No additional labour was required for either solution.

TABLE 14. COMPARISON OF SOLUTIONS: CASE 3

Activity	Solution 1	Solution 2
Gross margin ($)	$25,000	$25,212
Flax (ac)	586	586
Clover (ac)	293	293
Fallow (ac)	293	293
Cows - sell calves	8	7
Fatten calves	67	79
Buy land (ac)	352	3352
Machinery costs for solution 1 ($)	5,680	-
Labour costs for solution 2 ($)	-	0
Comparable gross margin ($)	19,320	25,212

TABLE 15. MACHINERY REQUIRED FOR CASE 3 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable HP)	84	25
Chisel plow - rod weeder (ac/hr)	7	2.4
Disker - press drill (ac/hr)	5	3.6
Combine (ac/day)	60	42

5.2.4 Case 4

Region: Olds

Weather station used: Calgary

Soil types: Medium to heavy

Tillage and seeding time (for wheat and barley):

May 1 - June 15 = 32 work days at 10 hrs/day
= 320 hours

Tillage and seeding machinery in sequence: Double disker
Chisel plow
Press drill
Harrow

Grain harvesting machinery: Swather
Combine

Results: See table 16 and 17.

Annual machinery costs for solution 1:

$1930 fixed cost for the tractor, and tillage and seeding machinery

500 fixed cost for the swather

5200 fixed and penalty costs of harvesting ($5.00/acre for 654 acres).

Labour costs for solution 2:

$780 for livestock

TABLE 16. COMPARISON OF SOLUTIONS: CASE 4

Activity	Solution 1	Solution 2
Gross margin ($)	29,977	28,531
Buy land (ac)	129	224
Breakland (ac)	40	40
Barley (ac)	327	374
Wheat (ac)	327	374
Sell weanlings (sow unit)	162	139
Sell fat pigs (sow unit)	-	23
Machinery costs for solution 1 ($)	7,630	-
Labour costs for solution 2 ($)	-	780
Comparable gross margin ($)	22,347	27,751

TABLE 17. MACHINERY REQUIRED FOR CASE 4 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable HP)	58	43
Double disk (ac/hr)	6	11.6
Chisel plow (ac/hr)	5.5	4.8
Press drill (ac/hr)	7	10.2
Harrow (ac/hr)	12	27.2
Combine (ac/day)	25	53

5.2.5 Case 5

Region: Red Deer

Weather station used: Edmonton

Soil types: Medium to heavy

Tillage and seeding time (for oat greenfeed):

May 1 - June 30 = 44 work days at 10 hrs/day
= 440 hours

Tillage and seeding machinery in sequence:

Chisel plow
Press drill and packers in tandem

Forage harvesting machinery: Forage harvester
Wagon

Results: See tables 18 and 19.

Annual machinery costs for solution 1:

$2460 fixed costs for the tractor, and tillage and seeding machinery

805 fixed costs for the forage harvester and wagon

For solution 2, the forage harvester and wagon were both included at 83% of the annual fixed cost or $1.30/acre and $0.09/acre respectively. The seeding equipment is unreasonably small and should be rented. The tractor was sized to handle the forage harvester.

Labour costs for solution 2.

$400 for livestock

TABLE 18. COMPARISON OF SOLUTIONS: CASE 5

Activity	Solution 1	Solution 2
Gross margin ($)	32,711	32,126
Legume silage (ac)	279	279
Oat silage (ac)	56	56
Fatten steer calves	39	39
Grow and fatten heifer calves	336	336
Fatten yearling steers	197	197
Machinery costs for solution 1 ($)	3,265	-
Labour costs for solution 2 ($)	-	400
Comparable gross margin ($)	29,446	31,726

TABLE 19. MACHINERY REQUIRED FOR CASE 5 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable)	90*	27
Chisel plow (ac/hr)	5.5	0.2
Press drill and packers (ac/hr)	7	0.4

* Estimated

5.2.6 Case 6

Region: Vulcan - Arrowwood

Weather station used: Calgary

Soil types: Medium to heavy

Tillage and seeding time (for grain crops):

April 8 - June 21 = 46 work days at 10 hrs/day
= 460 hours

Tillage and seeding machinery in sequence:

One-way dikser and packers in tandem
Harrows

Grain harvesting machinery: Swather (same as for hay crops)
Combine

Fallow: worked with double disk during seeding

Haying machinery: Baler
Swather

Results:

For solution 1, the machinery inventory was not available so the comparable gross margin could not be calculated. For solution 2, no additional labour needed to be hired. However, the machinery was small and should probably be rented. The baler cost \$.55/acre or 6% of the total yearly fixed cost.

TABLE 20. COMPARISON OF SOLUTIONS: CASE 6

Activity	Solution 1	Solution 2
Gross margin (\$)	14,962	16,276
Buy land (ac)	281	281
Flax (ac)	269	182
Barley (ac)	83	28
Fallow (ac)	269	353
Wheat (ac)	36	231
Oats (ac)	8	-
Hay (ac)	190	73
Oat hay (ac)	22	-
Fatten steer calves	-	17
Fatten long yearly steers	80	8
Fatten yearling steers	62	80
Keep cows - sell calves	-	47

Continued.....

TABLE 20. CONTINUED

Machinery cost for solution 1 ($)	NA	-
Labour cost for solution 2 ($)	-	0
Comparable gross margin ($)	NA	16,276

TABLE 21. MACHINERY REQUIRED FOR CASE 6 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable HP)	*	14
One-way disker (ac/hr)	*	1.4
Harrow (ac/hr)	*	8.2
Double disk (ac/hr)	*	3.8
Combine (ac/day)	*	31

* This information was not available for this case study

5.2.7 Case 7

Region: Red Deer

Weather station used: Edmonton

Soil types: Medium to heavy

Tillage and seeding time (for grain crops):

May 1 - 30 = 23 work days at 10 hrs/day
= 230 hours

Tillage and seeding machinery in sequence:

Double disker (used three times in sequence)
Press drill
Harrow

Grain harvesting machinery: Swather
Combine

Haying machinery: Forage harvester
Wagon

Results:

Annual machinery costs for solution 1:

$2675 fixed costs for the tractor, and tillage and seeding machinery

710 fixed cost for the swather

1135 fixed costs for the forage harvester, wagon, and baler

7100 fixed and penalty costs of harvesting ($4.60/acre for 1544 acres)

Labour costs for solution 1:

$1000 for seeding

800 for haying

560 for harvesting

Labour costs for solution 2:

$ 280 for harvesting

1140 for livestock

TABLE 22. COMPARISON OF SOLUTIONS: CASE 7

Activity	Solution 1	Solution 2
Gross margin ($)	100,900	88,449
Buy land (ac)	1,250	1,269
Wheat (ac)	441	445
Oats (ac)	221	222
Barley (ac)	882	889
Legume hay (ac)	409	475
Legume silage (ac)	170	61
Fatten steer calves	369	132
Fatten yearling steers	696	903
Machinery costs for solution 1 ($)	11,620	-
Labour costs for solution 1 ($)	2,360	-
Labour costs for solution 2 ($)	-	1,420
Comparable gross margin ($)	86,920	87,029

TABLE 23. MACHINERY REQUIRED FOR CASE 7 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable HP)	83	102
Double disker (ac/hr)	8	10
Press drill (ac/hr)	12	27
Harrow (ac/hr)	24	72
Combine (ac/day)	*	110

* not available

5.2.8 Case 8

Region: Spirit River

Weather station used: Fairview

Soil types: Medium to heavy

Tillage and seeding time (for barley):

May 1 - June 20 = 40 work days at 10 hrs/day
= 400 hours

Tillage and seeding machinery in sequence:

Chisel plow
Harrow
Press drill
Harrow

Grain harvesting machinery: Swather
Combine

Results: See tables 24 and 25.

Annual machinery costs for solution 1:

$1330 fixed cost for the tractor, and tillage and seeding machinery

500 fixed cost for the swather

2230 fixed and penalty costs of harvesting ($6.00/acre for 372 acres)

For solution 2, no seeding machinery was included because crops which needed to be seeded were not selected. A swather and combine were included to harvest the fescue. No additional labour was required for either solution.

TABLE 24. COMPARISON OF SOLUTIONS: CASE 8

Activity	Solution 1	Solution 2
Gross margin ($)	11,330	11,561
Buy land (ac)	155	204
Creeping red fescue (ac)	276	454
Barley (ac)	15.6	0
La Salle clover (ac)	81	0
Fallow (ac)	32.2	0
Sell weanlings (sow unit)	12	0
Machinery costs for solution 1 ($)	4,060	-
Labour costs for solution 2 ($)	-	0
Comparable gross margin ($)	7,270	11,561

TABLE 25. MACHINERY REQUIRED FOR CASE 8 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable HP)	40	0
Chisel plow (ac/hr)	5.5	0
Press drill (ac/hr)	6	0
Harrow (ac/hr)	12	0
Combine (ac/day)	60*	32

* Estimated

5.2.9 Case 9

Region: Athabaska

Weather station used: Beaverlodge

Soil types: Medium to heavy

Tillage and seeding time (grain crops):

May 10 - June 10 = 25 work days at 10 hrs/day
= 250 hours

Tillage and seeding machinery in sequence:

Chisel plow
Press drill

Grain harvesting machinery: Swather (same as used for hay)
Combine

Haying machinery: Swather
Baler

Results: See table 26 and 27.

Annual machinery costs for solution 1:

$1760 fixed costs for the tractor, and tillage and seeding machinery

710 fixed cost for the swather

330 fixed cost for the baler

1870 fixed and penalty costs of harvesting ($7.50/acre for 249 acres)

Labour costs for solution 2:

$1180 for livestock

TABLE 26. COMPARISON OF SOLUTIONS: CASE 9

Activity	Solution 1	Solution 2
Gross margin ($)	17,200	14,968
Buy land (ac)	-	188
Break land (ac)	75	75
Wheat on grass (ac)	83	83
Barley on stubble (ac)	83	83
Oats on stubble (ac)	83	83
Hay (ac)	170	170
Sows - sell weanlings	61	86
Cows - sell calves	40	40
Fatten long yearling steers	46	-

Continued.....

TABLE 26. CONTINUED

Machinery fixed costs for solution 1 ($)	4,670	-
Labour costs for solution 2 ($)	-	1,180
Comparable gross margin ($)	12,530	13,788

TABLE 27. MACHINERY REQUIRED FOR CASE 9 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable HP)	61	13
Chisel plow (ac/hr)	5.5	1.5
Press drill (ac/hr)	7.5	3.2
Combine (ac/day)	56	18

5.2.10 Case 10

Region: High Prairie

Weather station used: Beaverlodge

Soil types: Medium to heavy

Tillage and seeding time:

May 7 - June 10 = 27 work days at 10 hrs/day
= 270 hours

Tillage and seeding machinery in sequence:

Chisel plow and harrows in tandem
Harrows
Press drill

Grain harvesting machinery: Swather (same as used for hay)
Combine

Haying machinery: Swather
Custom baled

Results: See tables 28 and 29.

Annual machinery costs for solution 1:

$1420 fixed costs for the tractors, and tillage and seeding machinery

710 fixed cost for the swather

3680 fixed and penalty costs of harvesting ($4.60/acre for 800 acres)

Labour costs for solution 1:

$500 for seeding

280 for harvesting

Labour costs for solution 2:

$820 for livestock

TABLE 28. COMPARISON OF SOLUTIONS: CASE 10:

Activity	Solution 1	Solution 2
Gross margin ($)	52,200	48,353
Barley (ac)	100	100
Oats (ac)	100	100
Commerical fescue (ac)	450	450
Registered fescue (ac)	150	150
Sell weanling hogs (sow unit)	75	170
Sell breeding stock (sow unit)	13	-
Machinery costs for solution 1 ($)	5,810	-
Labour costs for solution 1 ($)	780	-
Labour costs for solution 2 ($)	-	820
Comparable gross margin ($)	45,610	47,533

TABLE 29. MACHINERY REQUIRED FOR CASE 10 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable HP)	37	12
Chisel plow with harrows (ac/hr)	5.5	1.2
Harrows (ac/hr)	18	7.3
Drill (ac/hr)	8.5	2.7
Combine (ac/day)	70*	57

* Estimated

5.2.11 Case 12

Region: Athabaska

Weather station used: Beaverlodge

Soil types: Medium to heavy

Tillage and seeding time:

May 10 - June 10 = 25 work days at 10 hrs/day
= 250 hours

Tillage and seeding machinery in sequence: Chisel plow
Disker
Press drill
Harrows

Grain harvesting machinery: Swather (same as for hay harvesting)
Combine

Forage harvesting machinery: Swather
Forage harvester
Wagon

Results: See tables 30 and 31.

Annual machinery costs for solution 1:

$3330	fixed costs for the tractor, and tillage and seeding machinery
710	fixed cost for the swather
805	fixed costs for the forage harvester and wagon
1955	fixed and penalty costs of harvesting ($5.00/acre for 391 acres)

For solution 2, only 34% of the swather costs were included and only 10% of the cost of a forage harvester and wagon were included.

Swather	$.18/ac
Forage harvester	$.87/ac
Self unloading wagon	$.48/ac

These costs are probably comparable with the fixed cost charge included in machinery rental prices.

Labour costs for solution 2:

$1180 for livestock

TABLE 30. COMPARISON OF SOLUTIONS: CASE 12

Activity	Solution 1	Solution 2
Gross margin ($)	10,574	7,986
Highland grazing (ac)	180	142
Highland silage (ac)	-	60
Highland barley (ac)	137	137
Highland oats (ac)	68	68
Lowland silage (ac)	59	-
Lowland barley (ac)	125	-
Lowland oats (ac)	62	-
Fatten calves	89	89
Cow - calf	90	90
Machinery costs for solution 1 ($)	6,800	-
Labour costs for solution 2 ($)	-	1,180
Comparable gross margin ($)	3,774	6,806

TABLE 31. MACHINERY REQUIRED FOR CASE 12 SOLUTIONS

Machine	Solution 1	Solution 2
Tractor (usable HP)	125	16
Chisel plow (ac/hr)	7	1.7
Double disker (ac/hr)	5	4.3
Press drill (ac/hr)	6	3.6
Harrows (ac/hr)	15	2.5
Combine (ac/day)	60	15

5.3 Conclusions and Discussion of the Optimum Machinery Sizes

In all cases the comparable gross margin for solution 2 is greater than solution 1. This demonstrates that it is desirable to size machinery in conjunction with selecting farm activities rather than either picking machinery subsequent to decisions regarding farm activities or considering existing machinery as a constraint on farm activities. Solution 1 for some cases (eg. case number 1, 2 and 7) represents a labour intensive operation where double shifts are run to handle the same cropping program as solution 2 but with much smaller machinery. This would indicate that there is a trade-off between labour and machinery and that at some point it becomes more profitable to hire more labour than to buy larger machinery.

The results show that when machinery costs are included at the time farm activities are selected, some activities become less profitable.

The results also show that the sizes of some of the machines were too small in relation to the sizes of others. For example, harrows and press drills are often too small in relation to chisel plows and double diskers. Some farms have a lot of excess power while other do not have enough.

The optimum combine sizes are not very close to the sizes on the farms, however the farmers are not penalized very much for this because a 25% increase in combine capacity from the optimum size increases the total fixed and penalty costs per acre by only

\$.43 per acre (10.7%). A 25% decrease in capacity increases total costs by \$.22 per acre (5.4%). (See table 4 and figure 2.) Also the farmers may have some of their harvesting done by custom operators or do custom combining themselves.

The comparison of the optimum machine sizes to those actually on the farm is not completely valid for several reasons. Firstly, the machine sizes for solution 2 are not completely accurate because if the cost coefficients were improved, the time allocation for the different machines would be adjusted and result in a little different sizes. Secondly, a one-man operation was assumed in sizing the seeding machinery for solution 2 but most of the case studies had two or three tractors on the farm which indicates a multiple-man operation. Thirdly, the farming program given by Anderson (2) and used as a basis for calculating the optimum machine sizes may not be anything like the actual program of the farmer. However, if the constraints given by the farmer are accurate the results will show whether or not he should change his program to optimize his returns.

Two statistics which can be derived from the tables of the previous section are worth noting. They are the total yearly machinery fixed costs per acre of cultivated land, and the total yearly machinery fixed costs as a percentage of the comparable gross margin. (The comparable gross margin is gross margin minus labour costs, machinery fixed costs, and the fixed and penalty costs of harvesting.) Total yearly machinery fixed costs were

obtained from the machinery sizes of solution 2 in section 5.2 and the costs per unit capacity listed in tables C1 and C2. The comparable gross margins and total cultivated acres were also obtained from solution 2 in section 5.2. The data are summarized in table 32.

The average annual machinery fixed cost was about $4.50 per acre. The cost ranged from $1.83 to $6.82 per acre for the eleven case studies. Yearly machinery costs averaged about 17% of the comparable gross margin for the eleven case studies. The range was from 6.3% to 40.8%. It should be noted that the comparable gross margin is really close to being net income. The only costs which are not included are depreciation on buildings and land taxes.

One may conclude, then, that machinery fixed costs are significant costs in a farmer's budget. However, they are not critical. A 10% oversizing of machinery (as represented by a 10% increase in annual machinery fixed costs) will only mean a 1.4% decrease in comparable gross margin.

With respect to the procedure followed, it is interesting to note that only one iteration of the Lagrange multiplier - linear programming iterative procedure for each case study was needed to determine the optimum machinery sizes. This was because the post-optimal information showed that the solution would not change if the cost coefficients were improved.

TABLE 32. YEARLY MACHINERY FIXED COSTS IN RELATION TO FARM ACREAGE AND INCOME

Case number	Yearly machinery cost ($)	Total cultivated acres (ac)	Machinery cost per acre ($)	Comparable gross margin* ($)	Machinery cost as a % of comparable (%) gross margin
1	14,407	3,285	4.38	47,962	30.0
2	4,732	2,588	1.83	45,400	10.2
3	3,742	1,172	3.19	25,212	14.8
4	4,548	748	5.08	27,751	16.5
5	2,112	335	6.00	31,726	6.3
6	2,900	867	3.35	16,276	17.8
7	9,175	2,092	4.39	87,079	10.5
8	1,730	454	3.81	11,561	15.0
9	2,186	419	5.22	13,788	15.9
10	3,351	800	4.19	47,553	7.0
12	2,779	407	6.82	6,806	40.8
Total =	51,662	13,167	49.26	361,114	184.9
Mean =	4,700	1,200	4.48	32,800	16.8

* Comparable gross margin equals gross margin minus labour costs, yearly machinery fixed costs, and the fixed and penalty cost of harvesting

5.4 Problems Encountered in Using Separable Programming

Separable programming is a mathematical method which opens the way for the inclusion of product terms in a linear program. However, mathematically separable programming will not guarantee a global maximum (or minimum) for the objective function. It may give a solution which is a local maximum (or minimum).

MacHardy (13) has shown how product terms may be used for including both time and machinery capacity as variables in mathematical programming. This method would eliminate the use of the Lagrange multiplier - linear programming iterative procedure in solving for optimum machine sizes.

MacHardy (13) demonstrated the method using integer programming. However, the computer program package (15) available to the author did not allow the use of integer programming but did allow ordered input through the technique of separable programming. That is, each successive variable in a set of special variables describing a function could only enter the basis if the preceeding variable was at its upper limit. The author adapted MacHardy's (13) method to fit the computer program package (15).

Although the system appeared to be workable, in practice it was not. One of the first problems encountered was that with only one machine to be sized and a fixed amount of available time the solution given did not make use of all the time available and had a large machine. This is obviously a less desirable solution than that of using all available time and having a smaller machine, (time was free and there was a cost associated with increasing machine size). This problem was overcome by "paying" the program a small amount (ten cents an hour) for each hour that came into the solution.

When two or more machines were included in the separable program the solution was usually not optimum. This could easily

be seen from the post-optimal information. The problem arises out of the fact that only the vector of a set of special vectors which is in the basis can be changed. In the solution given, changing the vectors in the basis would not change the gross margin. It was the vectors on either side of the one in the basis which would increase or decrease the gross margin. The program only considers the vectors in the solution and will not "look" two steps ahead.

The author also attempted to use the technique of ordered input to include non-linear fixed cost curves. This is illustrated by the fixed cost curve of figure 8 which is set up in matrix form in figure 9.

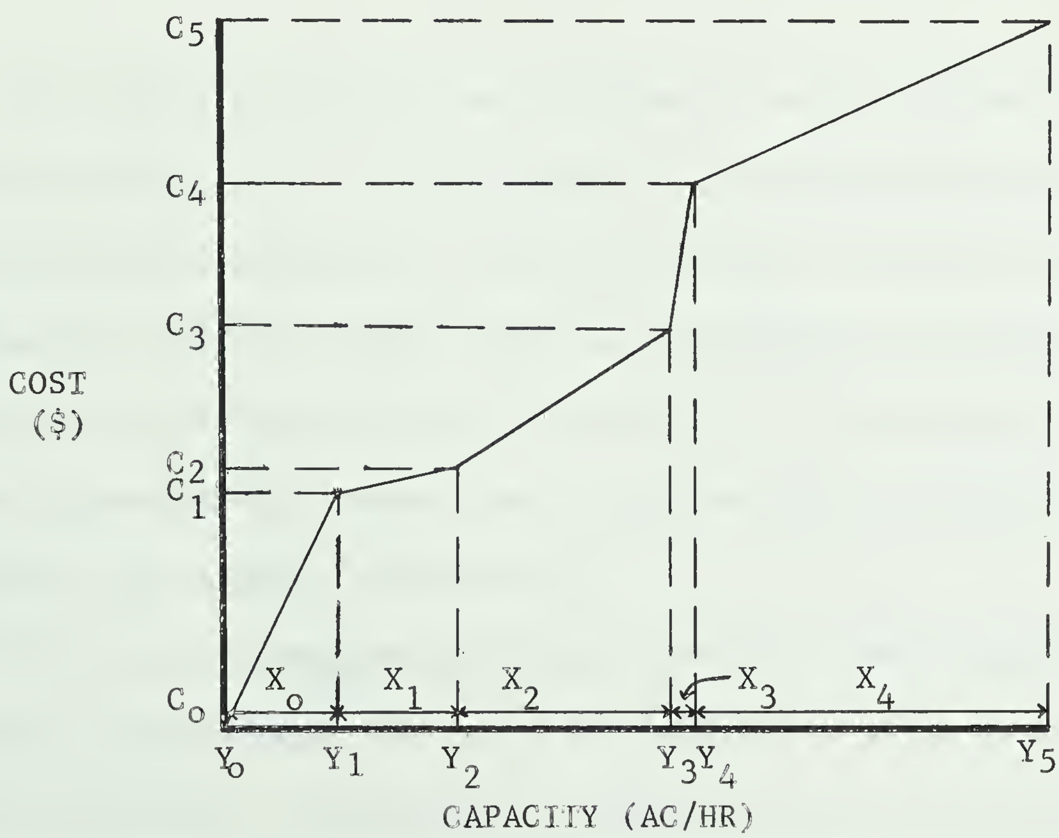


Figure 8. A non-linear fixed cost curve.

SPECIAL VECTORS

Y	X_o	X_1	X_2	X_3	X_4		RHS	
0	$-S_o$	$-S_1$	$-S_2$	$-S_3$	$-S_4$		Z	OBJECTIVE (MAXIMIZE)
-1	1	1	1	1	1	=	0	
	L_o	L_1	L_2	L_3	L_4			BOUNDS

where Y = machine size (ac/hr)

S_i = slope of the curve over the ith increment

L_i = upper limit for each special vector

Figure 9. Matrix setup for including a non-linear fixed cost curve in a mathematical program.

The format of figure 9 was tried with one of the case studies but the machine size and cost given in the solution were fixed at the junction between the vectors X_2 and X_3. The post-optimal information indicated that it was not profitable to include any of X_3 but it was profitable to include X_4. By reverting to the linear approximation method, one could show that the optimum solution fell along a section of X_4.

For most programming the author used the linear approximations. However, the technique did prove successful for including a total annual fixed cost (independent of machine size) by using the first two special vectors, X_o and X_1. X_o gave the complete cost and

X_1 was just to allow machine size to increase and to increase cost slightly. In figure 10 the first vector (X_o) will spread the total fixed cost over a reasonable acreage (50 acres). The second vector (X_1) will increase the cost by $1 for every additional 50 acres.

SPECIAL VECTORS

Column	1	2	3		4	
1	A	X_o	X_1		RHS	
2	+C	-500	-1	=	Z	OBJECTIVE (MAXIMIZE)
3	1	-50	-50		0	
		1				BOUNDS

where A = crop acreage

Figure 10. Matrix setup for including a fixed cost in a mathematical program.

This format is particularly useful in programming haying machinery where mower, rake and baler sizes are often either fixed or vary over a small range. The value of 50 in row 3 column 2 was found to be restrictive in some cases and should be set at a value such that the cost will enter at the same rate as the fixed cost per acre of renting the machine. Then if X_o enters as a fraction, the machine could be rented. If it enters completely, the total annual fixed cost of the machine will be included in the solution.

Normally fixed costs are included in mathematical programs using integer programming. However, as mentioned earlier, integer programming was not available in the computer package (15). Therefore the method shown above was used.

6. SENSITIVITY OF FARM ACTIVITIES TO MACHINERY SIZE CHANGES

6.1 The Techniques and Data Used

In order to determine the effect that machinery size changes had on the gross margin and the farm activities, Anderson's (2) linear program models were solved as they were set up except that the labour activities and restraints were excluded to allow for the inclusion of machinery activities.

MacHardy's (14) Lagrange multiplier - linear programming iterative procedure for sizing machinery was then used. The linear programs were set up and solved in 1967, before the product term method (13) mentioned in section 5.4 was developed and before the computer program (15) for solving separable programs was available. Also the simulation computer program (3) for determining the fixed costs of harvesting had not been written. For these reasons all of the machinery was included in the linear programs as one variable for each machine in the following relationship:

$$A \leq YT \qquad (1)$$

where A = sum of the acres to be covered or tons to be processed by that machine

Y = capacity in ac/hr or tons/hr

T = time in hours

This formula was used to relate the activities requiring a machine, the machine itself, and time. Both A and Y are free variables but T is fixed.

The Lagrange multiplier technique (14) for sizing machines used in sequence may be used for allocating time among machines, given the fixed costs of, and the acres to be covered by (or tons to be processed by) each machine. This technique was used to determine fixed time values for each machine based on either the solution to the program which did not include machinery or the previous solution which included machinery.

There are two types of restrictions which must be satisfied when solving the Lagrange multiplier technique for minimum cost machinery combinations. One is that the sum of the times allocated to the individual machines must be less than or equal to the total time allowed for the sequence of machines. The other is that the tractor must be large enough to pull each of the machines. (The latter restriction applies to towed implements only). However, MacHardy (14) has shown that the minimum cost solution is not always the one where the tractor is pulling its maximum load for all machines. Some machines may be smaller than the size necessary to load the tractor. In this case, the way to determine the least cost combination of machines is to guess which machines will load the tractor, solve the Lagrange multipliers, and check the solution. But, even if the solution is valid one does not know if it is the least cost

solution without trying all the other possible combinations of some machines loading the tractor and some not. One can see that the number of combinations increases rapidly as the number of machines used in conjunction with the tractor increases. For this reason the author wrote a computer program to solve all the combinations and pick the lowest cost valid solution. This computer program is contained in appendix D.

Machine horsepower requirements were taken from appendix B. Costs coefficients were those given in appendix C. It should be noted that the cost coefficient for tractors used in these programs was \$16.7 per horsepower and not \$21 per horsepower as given in appendix C. This is because the value of \$16.7 was based on maximum drawbar horsepower as given in the Nebraska Tractor Tests (16). A more accurate estimation of usable drawbar horsepower in the field was obtained after these linear programs were solved and is 65% of maximum belt horsepower. (See appendix C, section 2).

Outside time limits for field operations based on seasonal information given by Anderson (2) were chosen. Also the land management practice given by Anderson (2) was used as a basis for determining what type of machinery was to be used and which field machines would share the available time in a particular season.

Eleven of the twelve case studies used by Anderson (2) were used for this analysis. The linear programs were run once without any machinery. Then the Lagrange multiplier computer

program was run and time values for each machine ranging from 100% to 20% of the specified limit (in 20% increments) were obtained. Using these time values as input, the linear programs were solved for each of the five time values. The new solutions were then used as a basis for obtaining new input for the Lagrange multiplier computer program and the procedure was repeated. The next section contains the assumptions, results and observations for each case study for the solution which excludes machinery costs and for the solutions of the second run of the five time percentages.

A graph of gross margin vs time percentage is also shown with the results of each case study. The mean time shown on each graph was determined by calculating the ratio of the mean tillage and seeding time period of section 5.2 to the maximum tillage and seeding time period given in the following section and expressing this ratio as a percentage.

The graphs also have percent of machinery costs on the X axis. The cost percentages were obtained as follows:

$$Z = CY \qquad (2)$$

where Z = total cost of the machine (\$)

C = cost of machine per unit capacity (\$/ac/hr)

Y = machine capacity (ac/hr)

Combining (1) and (2) yields

$$Z = C\left(\frac{A}{T}\right) \qquad (3)$$

From equation (3) one can see that halving time (T) is equivalent to doubling the cost per unit capacity (C). The X axis showing percent of machinery costs was obtained by using this relationship and setting the machinery costs at mean time equal to 100%.

6.2 Eleven Case Studies With Observations

6.2.1 Case 1

Land management:

Tillage and seeding season:

May 1 - June 9 = 40 days at 12 hrs/day
= 480 hours

Tillage and seeding machinery in sequence:

One-way disk seeder
Harrows

Fallow machinery: Chisel plow

Grain harvesting season:

August 15 - September 30 = 45 days at 10 hrs/day
= 450 hours

Grain harvesting machinery in sequence: Swather
Combine

Assumption about machinery use:

Spring tillage and seeding equipment will handle cover crop machinery requirements. Flax may be harvested with the combine sized for the grain acreage.

Observations (see table 33 and figure 11):

As time decreased, fallow and cover crop increased and thus durum wheat on fallow replaced hard red spring wheat on stubble. At the 40% time level activities shifted from field crops requiring machinery to hay and pasture, and therefore larger animal enterprises. The decrease in gross margin is due to changes in animal and cropping activities as a result of the machinery requirements, as well as the increased machinery cost itself.

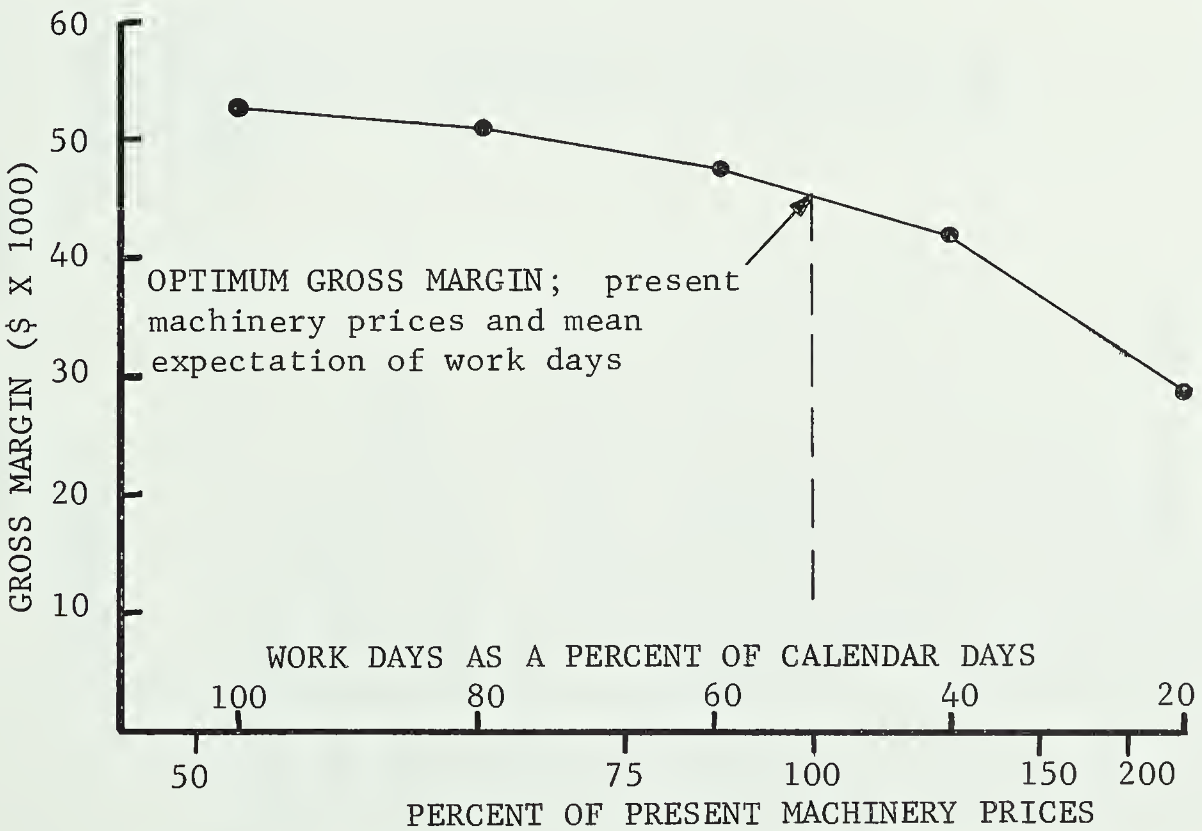


Figure 11. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 1.

TABLE 33. RESULTS OF CASE 1 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	61862	53178	51173	48112	42306	29700
2	Flax (fallow)(ac)	100	100	100	100	100	100
5	Durum wheat (fallow)(ac)	0	0	392	392	600	0
6	Wheat (stubble)(ac)	2385	2385	1600	1600	1185	235
9	Fallow (ac)	100	100	492	492	700	100
11	Cover crop for prod. (ac)	100	100	492	492	492	0
12	Tame hay (ac)	0	0	0	0	0	41.9
13	Tame pasture (ac)	0	0	0	0	0	776
14	Excess fallow (ac)	600	600	208	208	0	0
16	Winter grass (ac)	3123	3123	3201	3201	3243	4240
32	Cow - calf	240	240	240	240	240	333
33	Fatten calves	152	152	152	152	152	21
51	Buy land	1000	1000	1000	1000	1000	0
52	Tractor (HP)	-	38.7	40.7	54.1	77.1	28.4
53	Chisel plow (ac/hr)	-	.8	4.9	6.6	12.5	4.7
54	One-way disk seeder (ac/hr)	-	8.8	9.3	12.6	17.9	6.6
55	Harrow (ac/hr)	-	35.1	37.0	44.0	60.9	22.0
56	Swather (ac/hr)	-	15.3	15.9	21.3	28.6	7.5
57	Combine (ac/hr)	-	8.1	8.4	11.3	15.2	4.0

7.2.2 Case 2

Land management:

Tillage and seeding season:

May 1 - June 10 = 40 days at 12 hrs/day
= 480 hours

Tillage and seeding machinery in sequence:

Chisel plow with rod weeder attachment
Press drill

Fallow machinery: Chisel plow with rod weeder attachment
fallow must be cultivated during seeding

Grain harvesting season:

August 15 - September 30 = 45 days at 10 hrs/day
= 450 hours

Grain harvesting machinery in sequence: Swather
Combine

Assumptions about machinery use:

Spring tillage and seeding machinery will be used to seed cover crop.

Observations (see table 34 and figure 12):

Wheat on fallow replaced wheat on stubble at the 40% time level because firstly, seeding land every year took more machinery than seeding one year and fallowing the next, and secondly, the returns from fallow land were not much less favourable than the returns from stubble land. The activities in the solution changed from grain crops to hay crops at the 20% time level. However, the tractor and chisel plow were still needed because there was a minimum on fallow.

TABLE 34. RESULTS OF CASE 2 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	57065	49399	47481	44281	37865	28095
4	Durum on fallow (ac)	859	859	859	859	1294	0
6	Wheat on stubble (ac)	870	870	870	870	0	0
10	Fallow (ac)	859	859	859	859	1294	379
11	Excess fallow (ac)	0	0	0	0	435	249
12	Tame hay (ac)	0	0	0	0	0	1150
21	Cows - sell calves	200	200	200	200	200	200
22	Fatten calves	271	271	271	271	271	271
51	Buy land (ac)	1059	1059	1059	1059	1058	0
55	Rent winter pasture (ac)	1654	1654	1654	1654	1741	2000
57	Cover crop prod. (ac)	11.4	11.4	11.4	11.4	11.4	11.4
58	Tractor (HP)	-	87.9	109	151	264	112.2
59	Chisel plow-rod weeder (ac/hr)	-	7.8	9.6	13.4	23.4	9.9
60	Press drill (ac/hr)	-	11.7	15.0	18.3	20.6	0
61	Swather (ac/hr)	-	11.3	14.1	18.8	18.6	0
62	Combine (ac/hr)	-	5.8	7.3	9.7	11.7	0

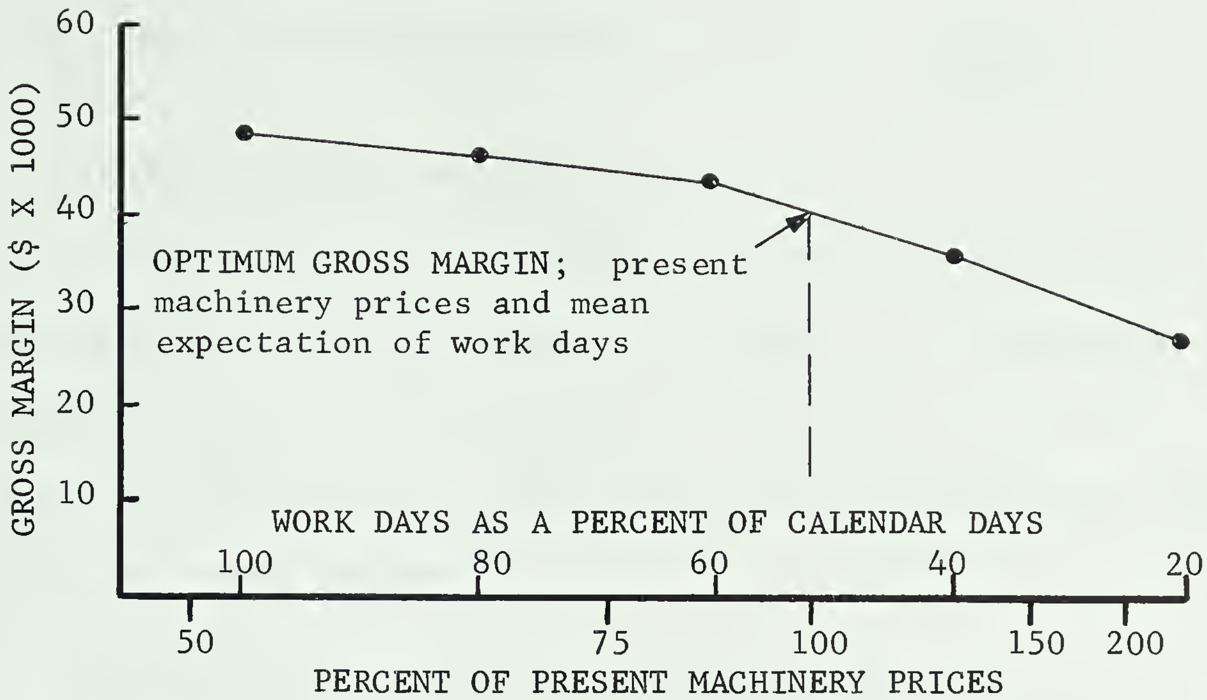


Figure 12. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 2.

6.2.3 Case 3

Land management:

Tillage and seeding season:

April 20 - June 10 = 50 days at 12 hrs/day
= 600 hours

Tillage and seeding machinery in sequence:

Chisel plow and rod weeder in tandem
Disker and press drill in tandem

Fallow machinery: Chisel plow and rod weeder in tandem

Haying season: Assume 20 days available at 10 hrs/day
= 200 hours

Haying machinery in sequence: Mower, rake and baler

Grain harvesting season:

September 1 - 30 = 30 days at 10 hrs/day
= 300 hours

Grain harvesting machinery in sequence: Swather
Combine

Assumptions about machinery use:

Spring tillage and seeding, and cultivating fallow will share time in the spring season. The swather and combine are needed for flax only (after the first computer run, this was changed to include wheat). The tractor used for seeding was large enough for haying equipment.

Observations (see table 35 and figure 13):

The solution did not change until the 40% time level where grass and tame pasture replaced activities requiring machinery.

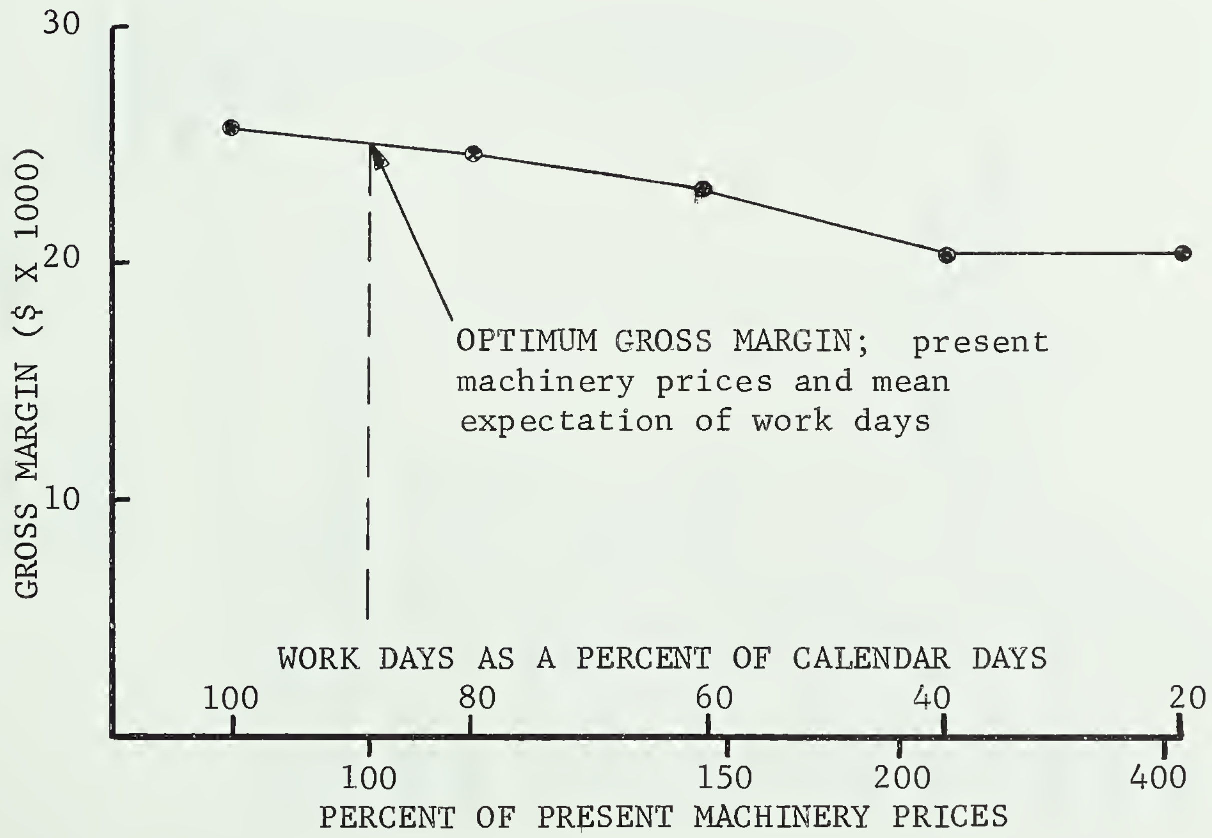


Figure 13. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 3.

TABLE 35. RESULTS OF CASE 3 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	29635	25804	24846	23250	20634	20634
3	Grain-clover-grain-fallow (4ac)	293	293	293	293	0	0
6	Flax on fallow (ac)	293	293	293	293	0	0
7	Durum on fallow (ac)	0	0	0	0	0	0
10	5 years grass (5ac)	0	0	0	0	234	234
15	Tame pasture (ac)	0	0	0	0	1171	1171
20	Flax on hay (ac)	293	293	293	293	0	0
21	Cows - sell calves	7.2	7.2	7.2	7.2	201	201
22	Fatten calves	79.5	79.5	79.5	79.5	79.5	79.5
45	Buy land (ac)	352	352	352	352	352	352
56	Tractor (HP)	-	20.6	25.7	34.3	0	0
57	Chisel plow - rod weeder (ac/hr)	-	1.5	1.9	2.5	0	0
58	Double disker - press drill (ac/hr)	-	2.7	3.4	4.5	0	0
59	Swather (ac/hr)	-	5.9	7.4	9.8	0	0
60	Combine (ac/hr)	-	2.9	3.6	4.9	0	0
61	Mower (ac/hr)	-	5.0	6.3	8.4	0	0
62	Rake (ac/hr)	-	5.1	6.3	8.4	0	0
63	Baler (ac/hr)	-	3.5	4.4	5.8	0	0

6.2.4 Case 4

Land management:

Tillage and seeding season:

April 25 - June 15 = 50 days at 12 hrs/day
= 600 hours

Tillage and seeding machinery in sequence:

Double Disker
Chisel plow
Press drill
Harrow

Grain harvesting season:

August 20 - September 30 = 40 days at 10 hrs/day
= 400 hours

Grain harvesting machinery in sequence: Swather and combine

Assumptions about machinery use:

Fall cultivation could be done with spring tillage and seeding machinery. No land was in fallow.

Observations (see table 36 and figure 14):

The activity mix shifted back and forth between different crops as available time decreased suggesting that there is a number of sub-optimal solutions close to the optimum.

TABLE 36. RESULTS OF CASE 4 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	36453	30794	29874	28419	25800	19806
1	4 yrs grain (4ac)	0	187	187	86.2	0	0
2	4 yrs grain-1 yr clover (5ac)	165	0	0	75	137	105
4	Wheat on stubble (ac)	331	374	374	247	137	105
5	Barley on stubble (ac)	331	374	374	322	273	209
7	Wheat on hay (ac)	165	0	0	0	0	0
8	Barley on hay (ac)	0	0	0	75	137	104
10	Break land (ac)	40	40	40	40	40	40
43	Weanling pigs	156.4	139	139	134	131	136
44	Litters of pigs	6.1	23.3	23.3	28	31.2	26.7
48	Buy land (ac)	303	224	224	195	159	0
51	Tractor (HP)	-	23.5	29.9	34.6	44	72.5
52	Double disk (ac/hr)	-	6.3	8.0	8.9	11.3	17.3
53	Chisel plow (ac/hr)	-	2.6	3.4	3.9	4.9	8.1
54	Press drill (ac/hr)	-	5.2	6.2	7.2	9.1	13.1
55	Harrow (ac/hr)	-	13.8	17.6	20.4	26.0	34.0
56	Swather (ac/hr)	-	5.7	7.1	8.1	9.9	15.2
57	Combine (ac/hr)	-	2.8	3.4	4.0	5.2	8.0

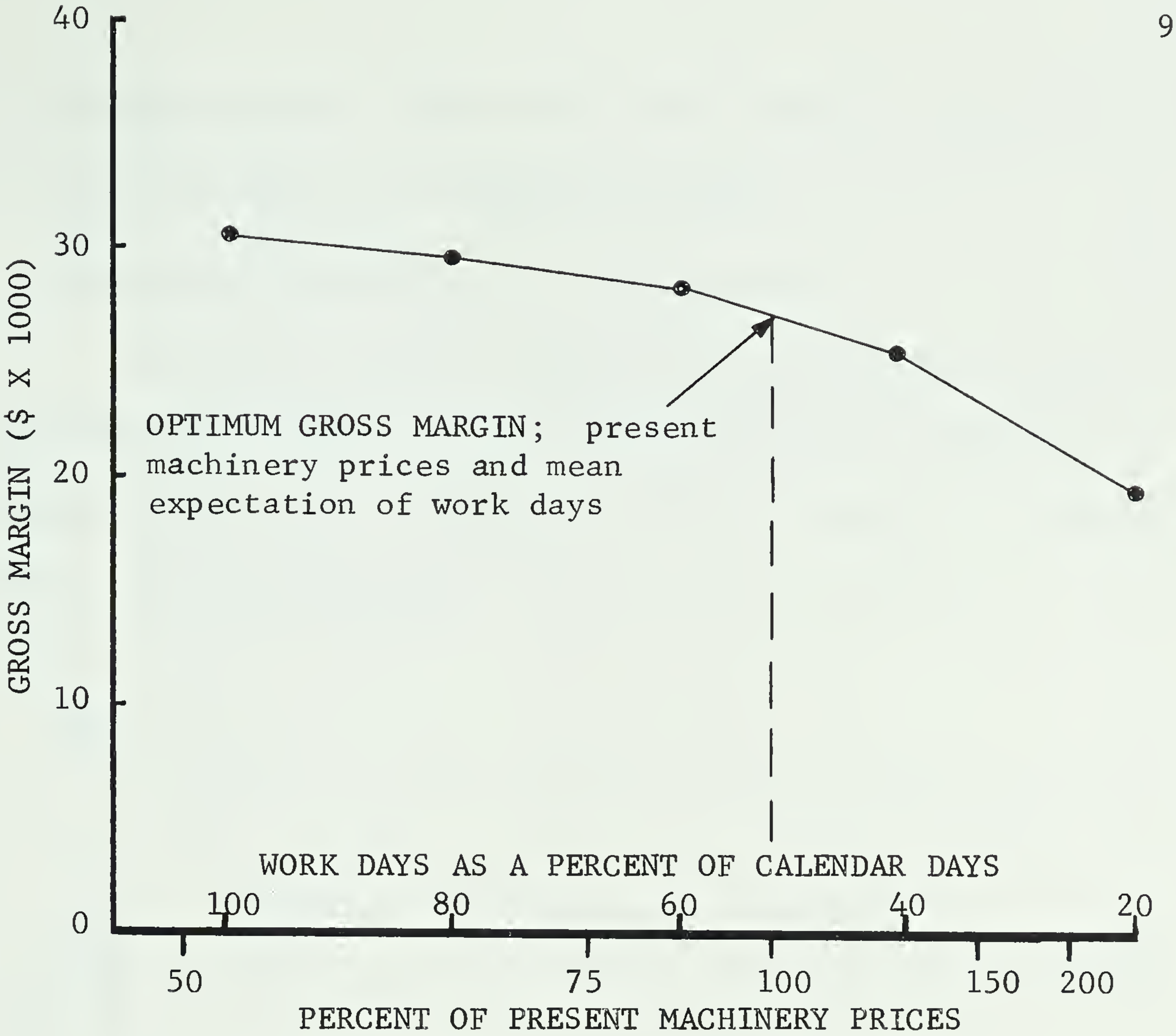


Figure 14. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 4.

6.2.5 Case 5

Land management:

Forage harvesting season:

June 25 - August 5 = 40 days at 10 hrs/day
= 400 hours

Forage harvesting machinery: Forage harvester and wagon

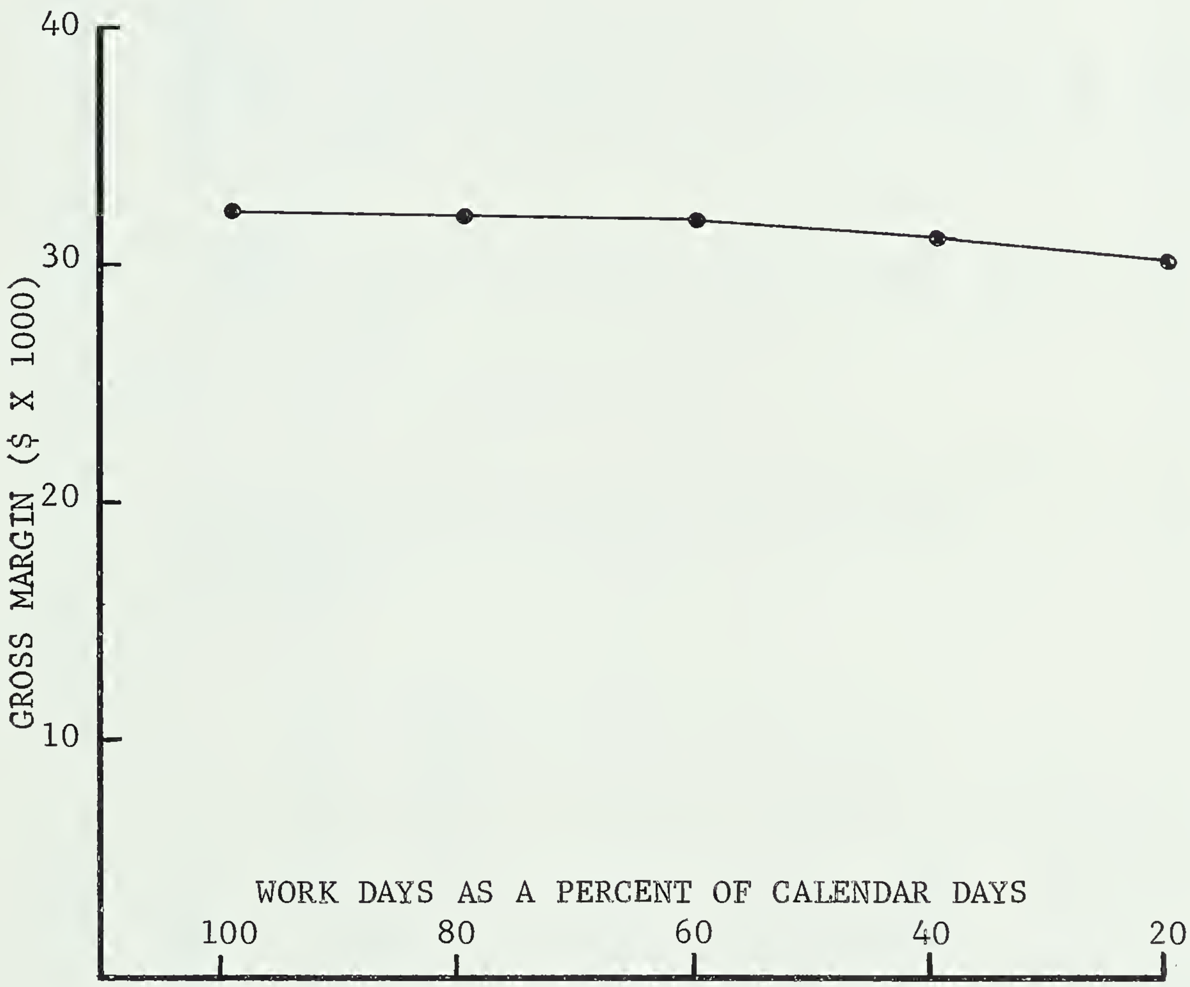
Assumptions about machinery use:

Since the acreage from the previous solution for seeding oat silage is small the tractor will be sized to take care of the forage harvester. It was assumed that the machinery needed would

be a forage harvester, wagon and tractor and that the spring tillage and seeding machinery was negligibly small.

Observations (see table 37 and figure 15):

The solution did not change until the 40% time level when legume hay (which did not require machinery) started to replace legume silage. However, it did not replace it completely, even at the 20% time level.



* Since there was no tillage and seeding season, mean expectation of days could not be determined.

Figure 15. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 5.

TABLE 37. RESULTS OF CASE 5 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	33181	32551	32393	32131	31606	30288
2	5 yr alfalfa 2 yr oats (7ac)	56	56	56	56	56	56
4	Oat silage (ac)	56	56	56	56	56	56
5	Legume silage (ac)	278	278	278	278	259	134
6	Legume hay (ac)	0	0	0	0	19.7	144
9	Fat heifer calves	336	336	336	336	323	200
10	Fat steer calves	39	39	39	39	51	108
12	Fat yearling steers	197	197	197	197	195	228
45	Tractor (HP)	-	11.6	14.5	19.4	27.7	36.8
46	Forage harvester (ton/hr)	-	4.7	5.8	7.8	11.1	14.7
47	Wagon (ton/hr)	-	7.8	9.8	13.1	18.6	24.7

6.2.6 Case 6

Land management:

Tillage and seeding season:

May 1- 30 = 30 days at 12 hrs/day
= 360 hours

Tillage and seeding machinery in sequence:

One-way disker and packers in tandem
Harrows

Fallow machinery: Double disk

Grain harvesting season:

August 20 - September 30 = 40 days at 10 hrs/day
= 400 hours

Harvesting machinery in sequence: Swather and combine

Assumptions about machinery use:

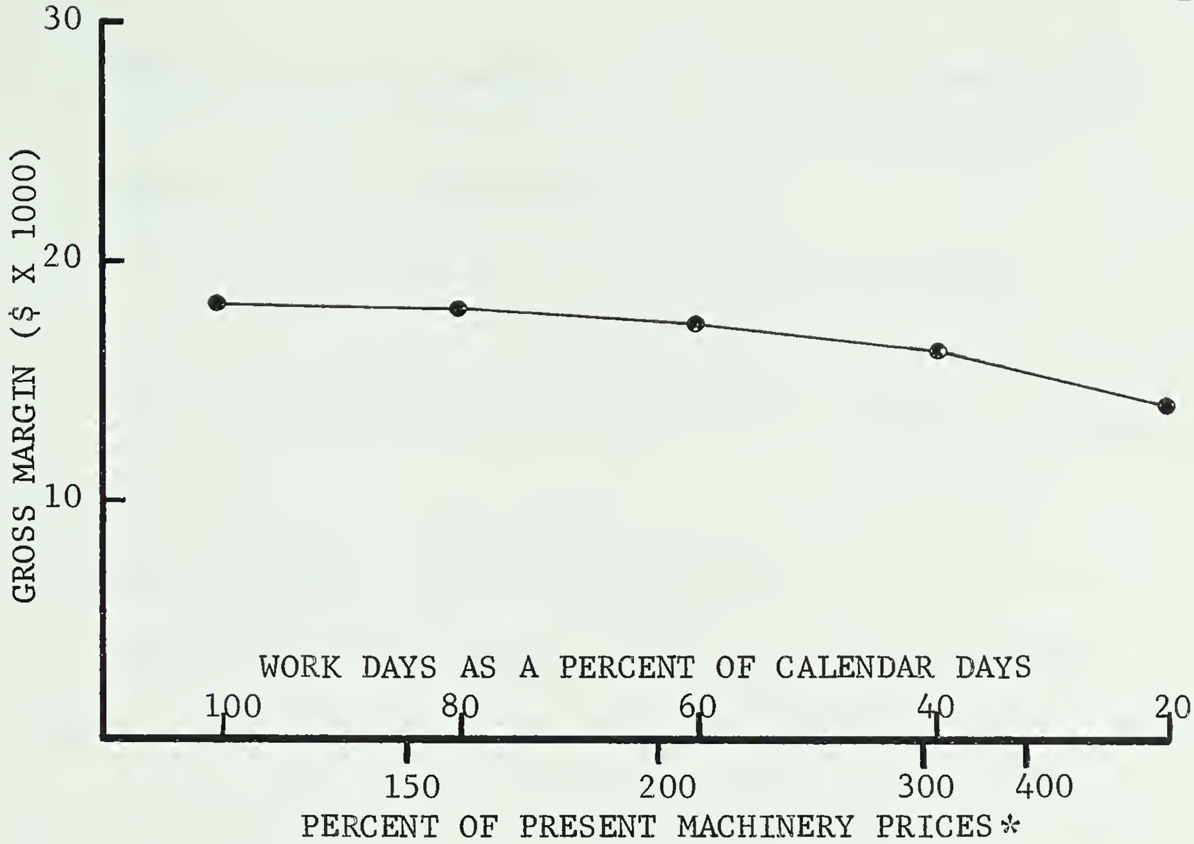
Flax may be harvested in October with the harvesting machinery sized for grain harvesting. Fallow will be cultivated in May.

Observations (see table 38 and figure 16):

When machinery was introduced there was a shift in the type of rotation used and the type of crops grown. Then, as machinery sizes increased, there was a shift away from stubble crops and toward crops grown on fallow. This shift occurred because crops grown on fallow did not require as much machinery relative to stubble crops (since only every second acre needed to be seeded each year) and thus the return per acre for crops on fallow eventually exceeded that of crops on stubble.

TABLE 38. RESULTS OF CASE 6 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	20156	18445	18132	17633	16658	14200
1	Grain-fallow (2ac)	0	281	281	281	283	283
2	Grain-grain-fallow (own)(3ac)	176	0	0	0	0	0
5	Buy land (rented)(ac)	0	250	257	260	286	286
6	Buy land (ac)	250	30.6	25	22	0	0
7	Grain fallow (rented)(2ac)	0	42.2	101	87	91	0
8	Grain-grain-fallow (rented)(3ac)	151	36.8	0	0	0	0
10	Grass-grass-grain-grain (rented)(4ac)	31	33.6	30	36	28	0
13	Flax on fallow (ac)	182	182	182	182	182	182
14	Durum on fallow (ac)	146	178	200	186	192	101
15	Wheat on stubble (ac)	52	54	28	44	34	0
16	Barley on stubble (ac)	339	50	33	28	22	0
21	Steer calves	35	31	20	17.4	13	48
23	Fatten yearling steers	80	80	80	80	80	80
26	Cow - calf	43	46	36	47.3	47	33
64	Tractor (HP)	-	19.7	24	31	46	60
65	One-way disker (ac/hr)	-	2.5	2.9	3.9	5.7	7.5
66	Harrow (ac/hr)	-	9.9	11.8	15.6	22.9	30.1
67	Double disk (ac/hr)	-	2.9	3.8	4.9	7.5	11.3
68	Swather (ac/hr)	-	2.1	2.5	3.3	4.7	3.8
69	Combine (ac/hr)	-	1.1	1.2	1.6	2.3	1.9



* Mean expectation of days at 128%

Figure 16. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 6.

6.2.7 Case 7

Land management:

Tillage and seeding season:

April 25 - June 10 = 45 days at 12 hrs/day
= 540 hours

Tillage and seeding machinery in sequence:

Double disker
Chisel plow
Double disker
Press drill
Harrows

Grain harvesting season:

August 25 - October 5 = 40 days at 10 hrs/day
= 400 hours

Grain harvesting machinery in sequence: Swather and combine

Hay and forage harvesting season:

June 25 - July 20 = 25 days at 10 hrs/day
= 250 hours

Hay and forage harvesting machinery: Baler
Forage harvester and wagon

Assumptions about machinery use:

Baling and silage making compete for time and bale stacking will be done after the forage harvesting season. The tractor sized for tillage and seeding operations will be used for forage harvesting and baling.

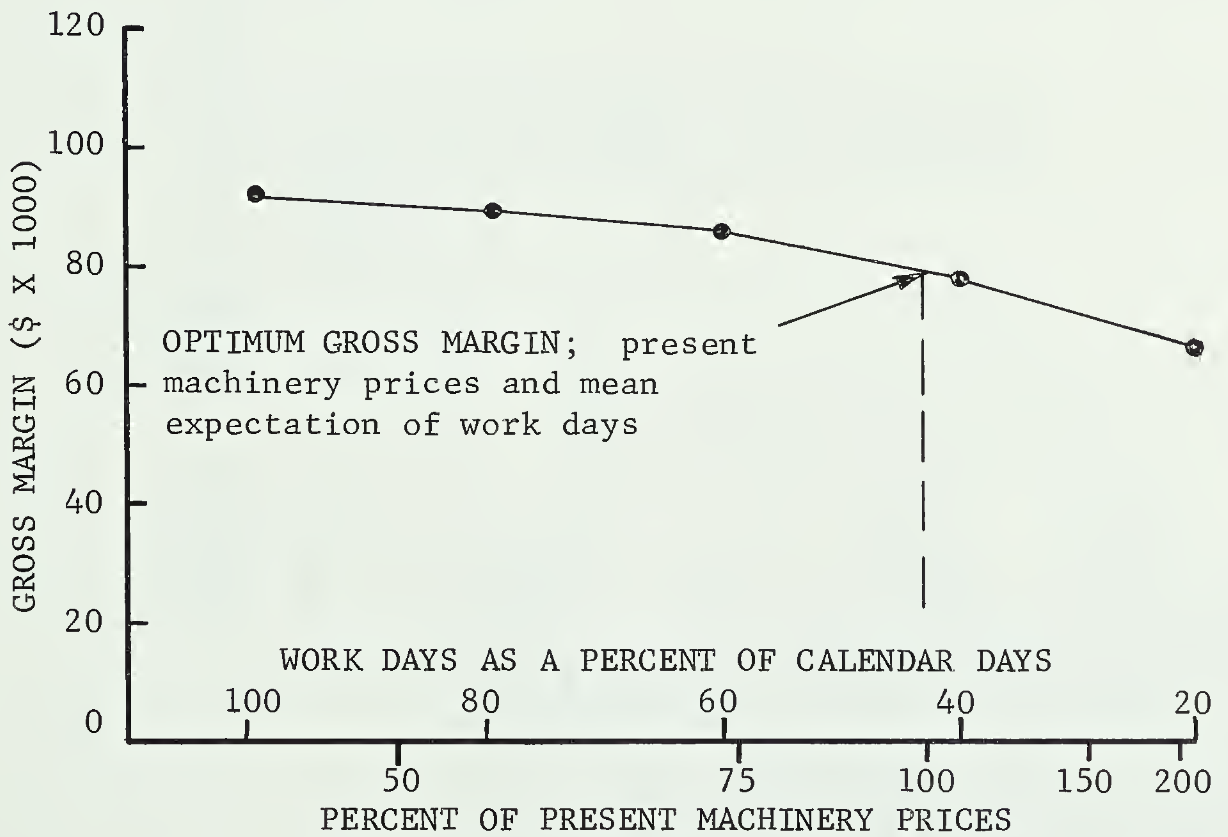


Figure 17. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 7.

TABLE 39. RESULTS OF CASE 7 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	101401	92387	90187	86628	79360	67676
1	3 yrs grain (3ac)	445	444	444	444	444	70
2	3 yrs grass-1 yr oats (4ac)	222	222	222	222	222	494
3	Wheat (ac)	445	444	444	444	444	0
4	Barley (ac)	889	888	888	888	888	141
5	Oats (ac)	222	194	194	194	194	565
6	Oat silage (ac)	0	28	28	28	28	0
7	Hay (ac)	476	518	518	518	518	1326
8	Legume silage (ac)	61	13.8	13.8	13.8	13.8	0
9	Pasture (ac)	131	134	134	134	134	157
15	Fatten steer calves	132	114	114	114	114	0
17	Fatten yearling steers	903	918	918	918	918	1014
38	Grass (maint)(ac)	632	0	0	0	0	0
50	Buy land (ac)	1269	1264	1264	1264	1264	1234
54	Tractor (HP)	-	68.1	84.6	120	180	138
55	Double disk (ac/hr)	-	9.1	11.3	16.1	24.1	32.1
56	Chisel plow (ac/hr)	-	7.7	9.5	13.5	20.2	15.6
57	Press drill (ac/hr)	-	12.6	15.9	18.8	28.2	23.5
58	Harrow (ac/hr)	-	35.8	45.4	52.7	79.1	66.1
59	Swather (ac/hr)	-	11.5	13.7	18.4	27.6	25.5
60	Combine (ac/hr)	-	5.7	7.2	9.7	14.6	13.5
61	Baler (ac/hr)	-	4.8	6.0	8.0	12.0	37.1
62	Forage harvester (ton/hr)	-	1.1	1.3	1.8	2.7	0
63	Wagon (ton/hr)	-	1.3	1.6	2.1	3.2	0

Observations (see table 39 and figure 17):

The solution did not have significant change until the 20% time level where both silage and wheat left the solution. The rotation changed, hay land increased and machinery sizes decreased.

6.2.8 Case 8

Land management:

Tillage and seeding season:

May 2 - 30 = 25 days at 12 hrs/day
= 300 hours

Tillage and seeding machinery in sequence:

Chisel plow
Harrows
Drill
Harrows

Fescue harvesting season:

July 1 - 30 = 30 days at 12 hrs/day
= 360 hours

Fescue harvesting machinery: Combine only

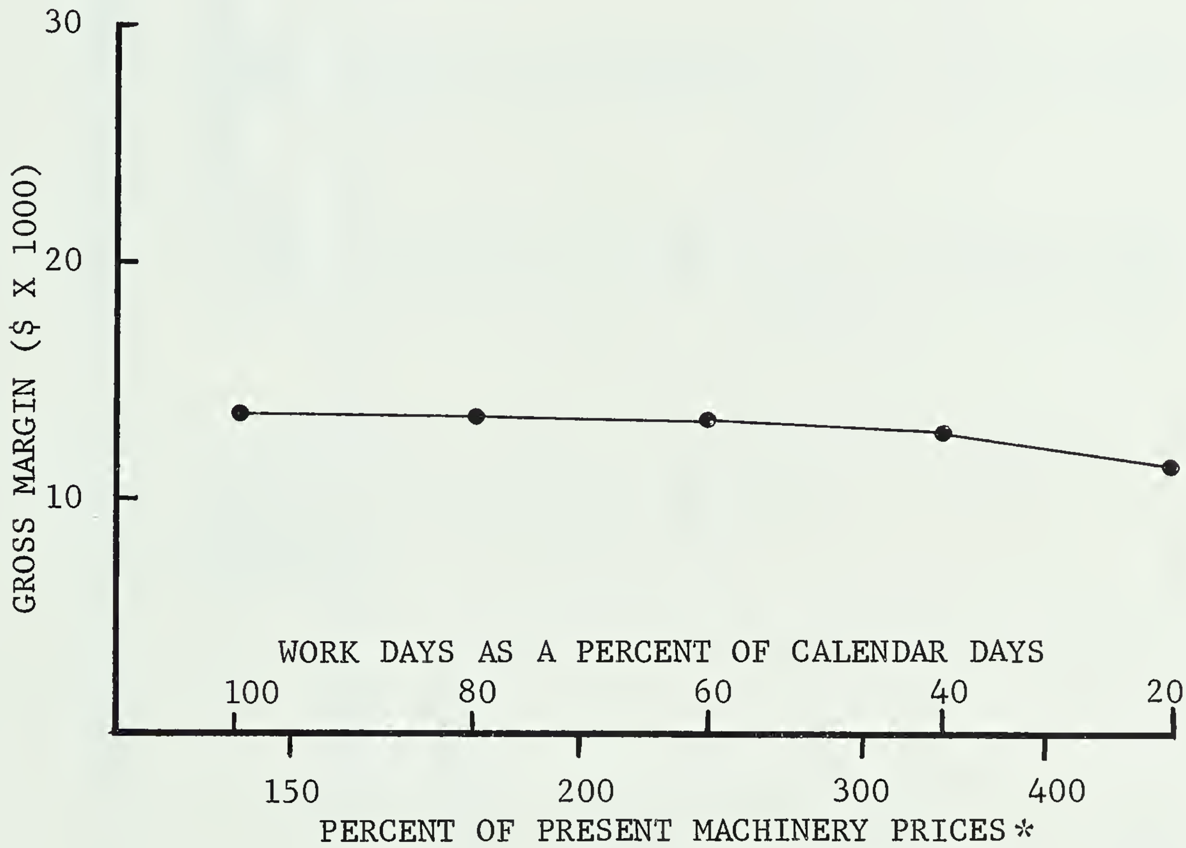
Fallow machinery: Chisel plow or double disk
Harrows (used after each operation of the chisel plow or double disk)

Assumptions about machinery use:

Fallow must be cultivated in the tillage and seeding season with the chisel plow and in the fescue harvesting season with the double disk. The tractor will be sized in relation to the seeding equipment and then checked to see if large enough for the disk used in July.

Observations (see table 40 and figure 18):

The solution did not change as time decreased and machine sizes increased. The machinery sizes are all very small and are therefore unrealistic but probably are a reasonable representation of the fixed cost of renting the machinery.



* Mean expectation of days at 133%

Figure 18. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 8.

TABLE 40. RESULTS OF CASE 8 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	14242	13728	13599	13385	12957	11671
2	3 yrs grain 1 yr fallow (4ac)	5.2	5.2	5.2	5.2	5.2	5.2
3	5 yrs grass (5ac)	81.4	81.4	81.4	81.4	81.4	81.4
5	Barley on fallow (ac)	5.2	5.1	5.1	5.1	5.1	5.1
7	Barley on stubble (ac)	10.4	10.4	10.4	10.4	10.4	10.4
9	Fescue (ac)	407	407	407	407	407	407
13	Buy land (ac)	178	177	177	177	177	177
29	Weanlings	12.5	12.5	12.5	12.5	12.5	12.5
57	Tractors (HP)	-	0.9	1.1	1.5	2.3	4.5
58	Chisel plow (ac/hr)	-	0.1	0.1	0.2	0.3	0.5
59	Press drill (ac/hr)	-	0.3	0.3	0.4	0.7	1.3
60	Harrows (ac/hr)	-	0.5	0.7	0.9	1.3	2.7
61	Combine (ac/hr)	-	1.2	1.5	2.1	3.1	6.2
62	Double disker (ac/hr)	-	0.2	0.2	0.3	0.4	0.8

6.2.9 Case 9 (use matrix with operating capital restriction)

Land management:

Tillage and seeding season:

May 1 - June 5 = 35 days at 12 hrs/day = 420 hours

Tillage and seeding machinery in sequence: Chisel plow
Press drill

Haying season: July 1 - 30 = 30 days at 10 hrs/day
= 300 hours

Haying machinery in sequence: Mower
Rake
Baler

Grain harvesting season:

August 25 - October 5 = 40 days at 10 hrs/day
= 400 hours

Grain harvesting machinery in sequence: Swather
Combine

Assumptions about machinery use:

Assume fall cultivation can be done with machinery sized for tillage and seeding.

Observations (see table 41 and figure 19):

As time decreased, some grain crops become less favourable while others become more favourable. Pasture and the animal enterprises increased. Haying left the solution at the 40% time level.

TABLE 41. RESULTS OF CASE 9 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	17808	15973	15604	15052	14551	13474
1	3 yrs grass-3 yrs grain (6ac)	114	83	76	62	60	60
3	Break land (ac)	75	75	32	0	0	0
4	Oats on hay (ac)	0	0	0	0	13.4	13.4
5	Barley on hay (ac)	0	0	0	50	47	47
6	Oats on stubble (ac)	114	83	76	88	77	77
7	Barley on stubble (ac)	114	83	76	37	44	44
8	Hay (ac)	262	170	148	57	0	0
9	Pasture (ac)	80	80	80	130	130	130
10	Wheat on grass (ac)	114	83	76	12	0	0
12	Sell weanling pigs	38	86	96	111	119	119
14	Cows - sell calves	40	40	40	65	65	65
53	Tractor (HP)	-	8.0	9.1	10.0	14.5	29
54	Chisel plow (ac/hr)	-	0.9	1.0	1.1	1.6	3.3
55	Press drill (ac/hr)	-	1.8	2.0	2.2	3.2	6.4
56	Swather (ac/hr)	-	1.9	2.2	1.7	2.3	4.6
57	Combine (ac/hr)	-	0.9	1.1	0.8	1.1	2.3
58	Mower (ac/hr)	-	2.4	2.6	1.3	0	0
59	Rake (ac/hr)	-	2.4	2.6	1.3	0	0
60	Baler (ton/hr)	-	2.2	2.4	1.2	0	0

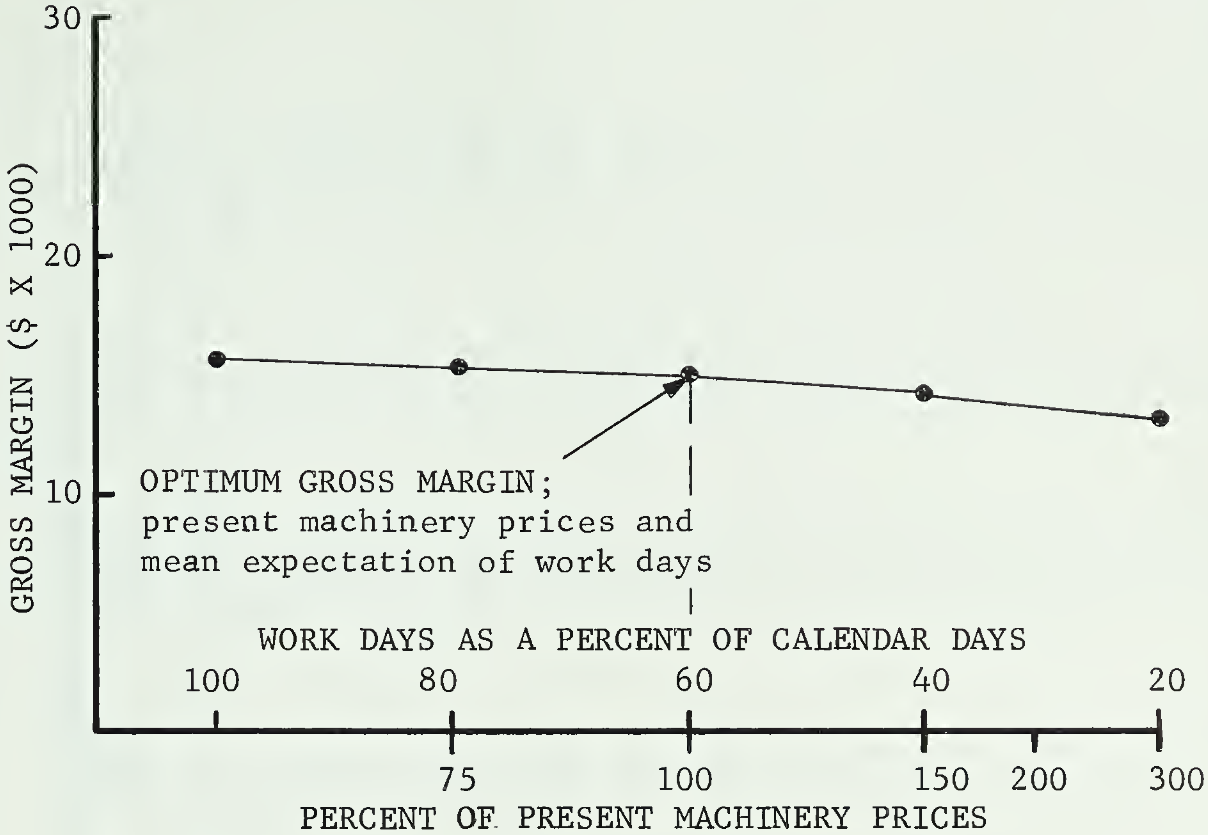


Figure 19. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 9.

6.2.10 Case 10

Land management:

Tillage and seeding season:

May 1 - June 5 = 35 days at 12 hrs/day
= 420 hours

Tillage and seeding machinery in sequence:

Chisel plow and harrows in tandem
Harrows
Press drill

Grain harvesting season:

August 25 - October 5 = 40 days at 10 hrs/day
= 400 hours

TABLE 42. RESULTS OF CASE 10 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	53213	50364	49652	48465	46092	38972
4	1 yr grain 3 yrs grass (4ac)	200	200	200	200	200	200
10	Reg. fescue (ac)	150	150	150	150	150	150
13	Barley on grass (ac)	100	100	100	100	100	100
14	Oats on grass (ac)	100	100	100	100	100	100
15	Fescue (ac)	450	450	450	450	450	450
20	Sell weanlings (sow)	170	170	170	170	170	170
63	Tractor (HP)	-	8.1	10.1	13.5	20.3	41.4
64	Chisel plow (ac/hr)	-	.8	1.0	1.3	2.0	4.0
65	Harrows (ac/hr)	-	4.4	5.5	7.3	11.0	22.5
66	Press drill (ac/hr)	-	1.7	2.1	2.8	4.1	7.9
67	Combine (ac/hr)	-	1.7	2.1	2.8	4.2	8.3
68	Swather (ac/hr)	-	4.6	5.7	7.6	11.3	22.5
69	Baler (ton/hr)	-	5.0	6.2	8.3	12.7	25.4

Grain harvesting machinery in sequence: Swather
Combine

Fescue harvesting season:

Combine July 1 - 30 = 30 days at 12 hrs/day
= 360 hours
Bale aftermath during grain harvesting season

Assumptions about machinery use:

The combine will be sized to harvest fescue and the swather and baler will compete for the time which is left after grain is harvested in the grain harvesting season.

Observations (see table 42 and figure 20):

The enterprise mix did not change at all when machine sizes increased. However, the machine sizes are not very large

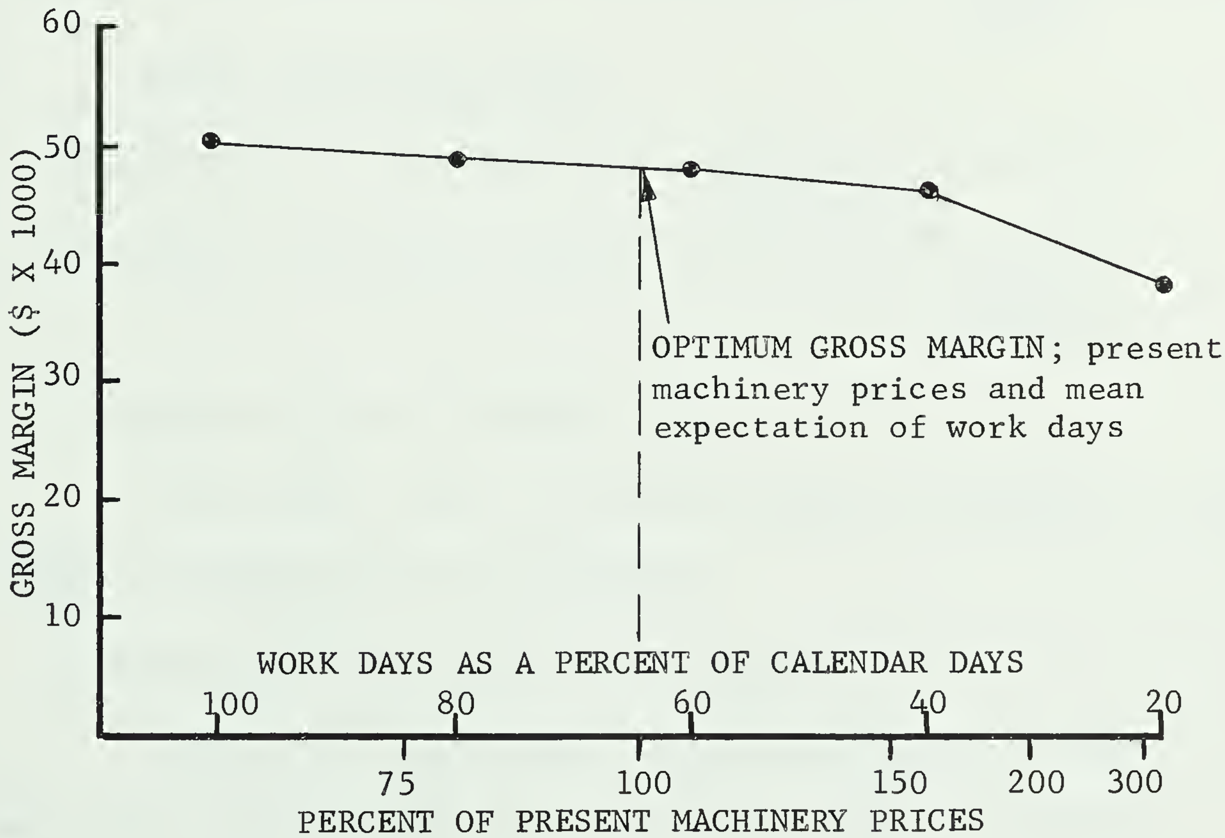


Figure 20. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 10.

6.2.11 Case 12 (use matrix for wet year with 90 head of cattle and $10,000 capital restriction)

Land management:

Tillage and seeding season:

May 1 - June 5 = 35 days at 12 hrs/day
= 420 hours

Tillage and seeding machinery in sequence:

Chisel plow
Double disk
Press drill
Harrow

Forage harvesting season:

July 1 - 30 = 30 days at 10 hrs/day
= 300 hours

Forage harvesting machinery in sequence: Forage harvester
Wagon

Grain harvesting season:

August 25 - September 30 = 35 days at 10 hrs/day
= 350 hours

Grain harvesting machinery in sequence: Swather
Combine

Assumptions about machinery use:

The tractor sized for spring tillage and seeding is large enough to handle the forage harvester.

Observations (see table 43 and figure 21):

Silage left the solution and the other crop acreages were upset when machinery was introduced. Then the solution remained constant until the 20% time level where crop acreages decreased slightly.

TABLE 43. RESULTS OF CASE 12 FOR VARIOUS TIME LEVELS

Column number	Activity	Solution without machinery costs	Percentage of maximum time				
			100%	80%	60%	40%	20%
	Gross margin ($)	10605	8996	8776	8407	7671	5471
1	Barley-barley-oats (3ac)	68.3	68.3	68.3	68.3	68.3	67.6
2	3 yrs grass (3ac)	68.3	68.3	68.3	68.3	68.3	67.6
3	Silage (ac)	59.3	0	0	0	0	0
4	Grazing (ac)	49.3	142.6	142.6	142.6	142.6	142.6
5	Barley-barley-oats (3ac)	62.2	0	0	0	0	0
6	3 yrs grass (3ac)	31.1	0	0	0	0	0
8	Grazing (ac)	93.3	0	0	0	0	0
9	Rough (ac)	110	110	110	110	110	110
18	Cow - calf	90	90	90	90	90	90
19	Winter calf	88.9	88.9	88.9	88.9	88.9	88.9
21	Yearling steers	0	0	0	0	0	0
42	Tractor (HP)	-	9.2	11.5	15.3	23.0	45.6
43	Chisel plow (ac/hr)	-	1.0	1.3	1.7	2.6	5.1
44	Double disker (ac/hr)	-	2.5	3.1	4.1	6.2	12.2
45	Press drill (ac/hr)	-	2.0	2.5	3.4	5.1	10.1
46	Harrow (ac/hr)	-	5.4	6.8	9.0	13.5	26.8
47	Forage harvester (ton/hr)	-	0	0	0	0	0
48	Wagon (ton/hr)	-	0	0	0	0	0
49	Swather (ac/hr)	-	1.8	2.2	3.0	4.4	8.7
50	Combine (ac/hr)	-	0.9	1.1	1.5	2.2	4.3

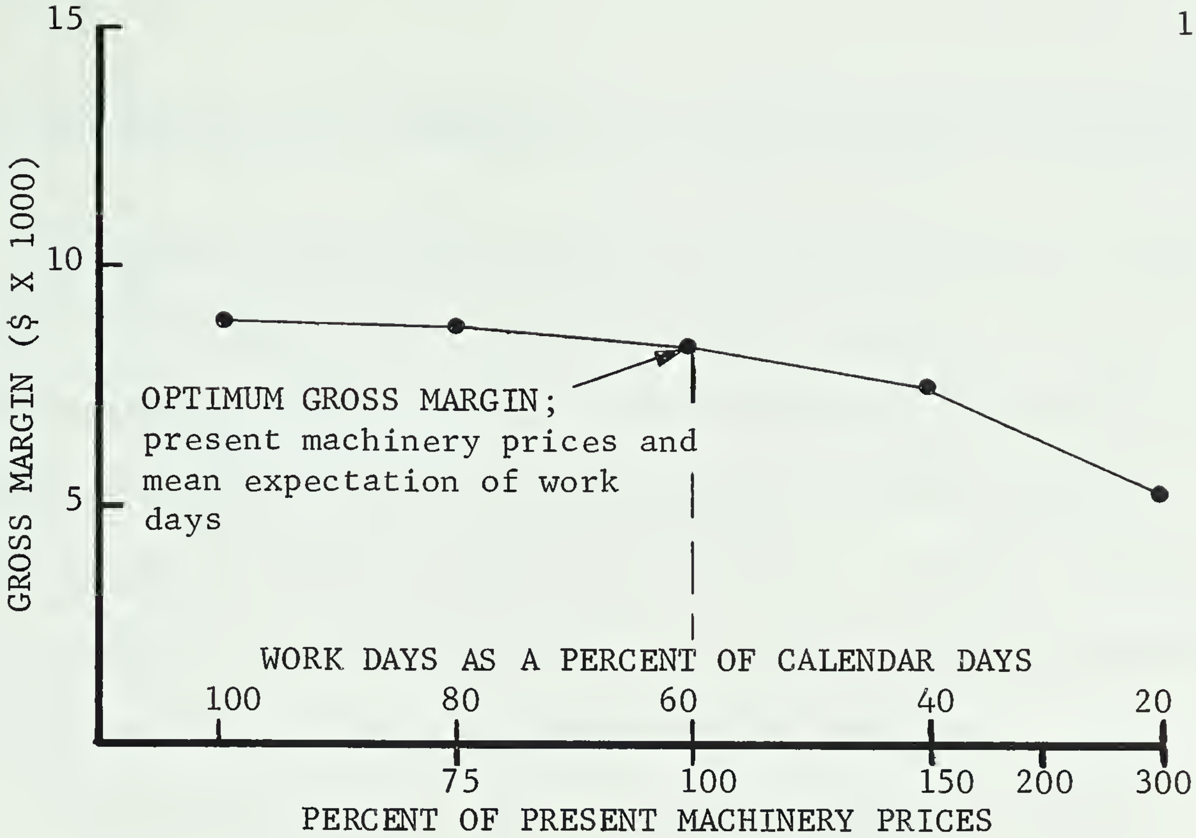


Figure 21. Changes in optimum gross margin with changes in machinery prices or with deviations from the mean expectation of work days - case 12.

6.3 Conclusions and Discussion of the Sensitivity Analysis

The gross margins of some programs were quite sensitive to changes in machinery prices, while the gross margins of other programs were not. In general, as prices increased the return from different crops in relation to each other changed and so the activity mix changed.

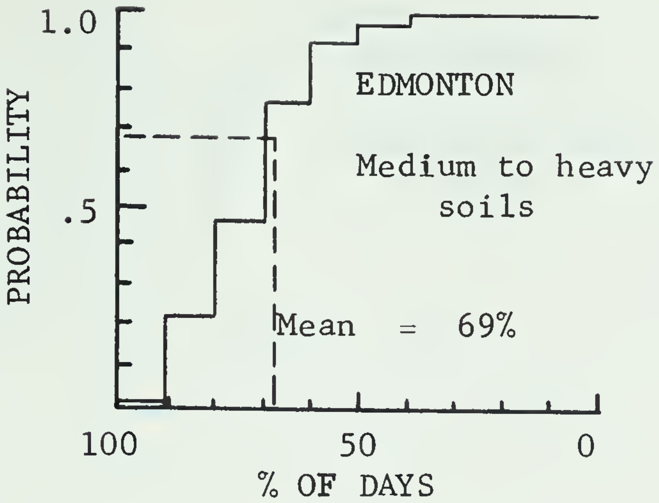
In some cases, the livestock program was almost as profitable as the cropping program so that there was a shift toward replacing cropping activities with livestock activities when machinery prices increased. At what price level this would occur could not be predicted from observing the optimal solution at todays level of machinery prices.

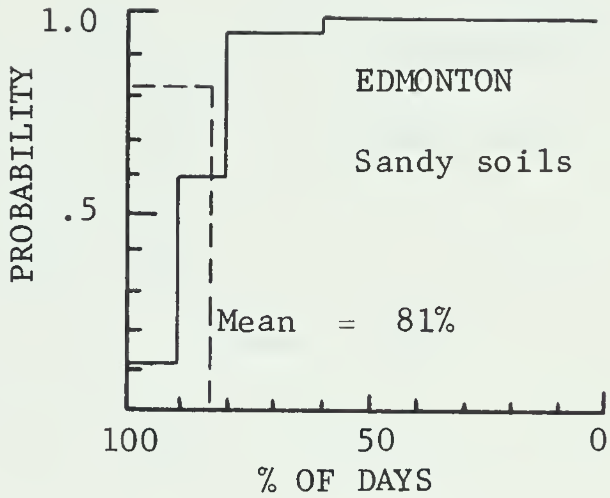
6.4 The Probability of Obtaining the Average Number of Work Days

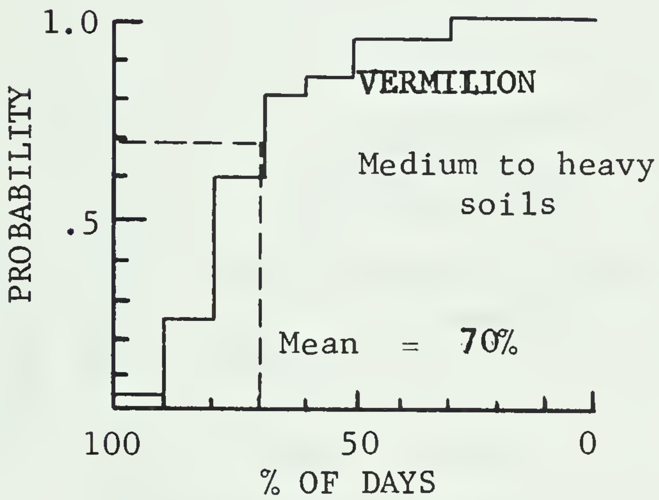
The graphs contained in section 6.2 show the affect on gross margin as machinery prices increase or with deviations from the mean expectation of work days. It is obvious that at work day percentages higher than the mean expectation a farmer would be gambling that he would be able to complete his seeding. Indeed, he is gambling, but with the odds in his favor that he can finish his seeding in just the mean expectation of work days.

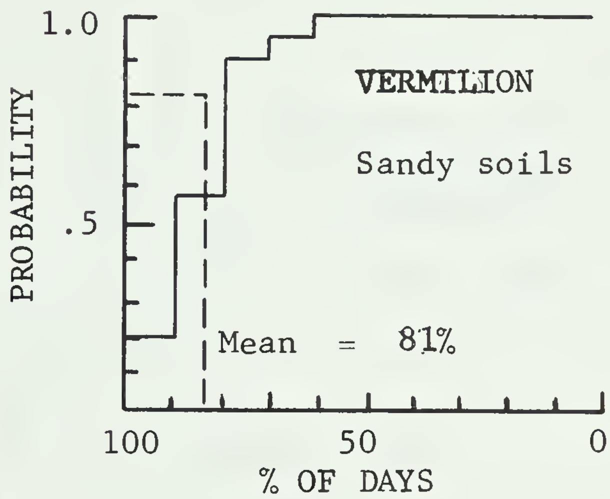
It would be useful to know what the probability is that a farmer could expect varying percentages of the maximum calendar days in a season to be work days. This would in effect give a measure of the likelihood that he could complete his seeding. The data given by Rutledge (19) and available on magnetic tape for work and non-work days was used as a basis for establishing the probability of obtaining any given percentage of the number of days between April 16 and June 15. A computer program was written to calculate and record the percentage of work days out of total calendar days in the period, for each year and weather station used by Rutledge (19). From this data cumulative histograms were drawn and are shown in figure 22.

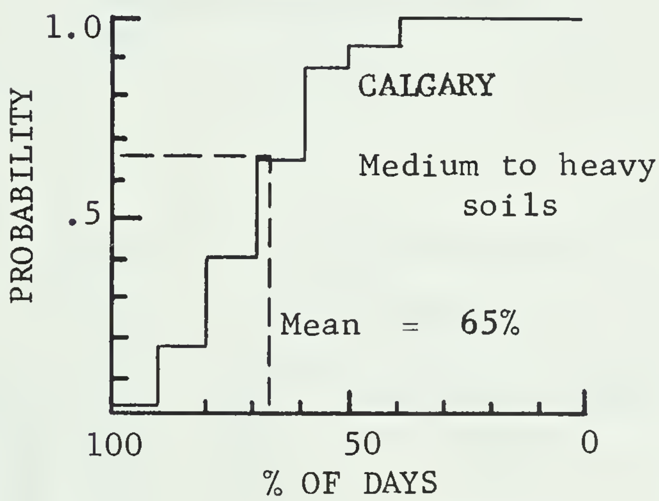
From this figure it is easily seen that the probability of obtaining 90% or more of the total days as work days is less than .1 for all stations on medium to heavy soils except

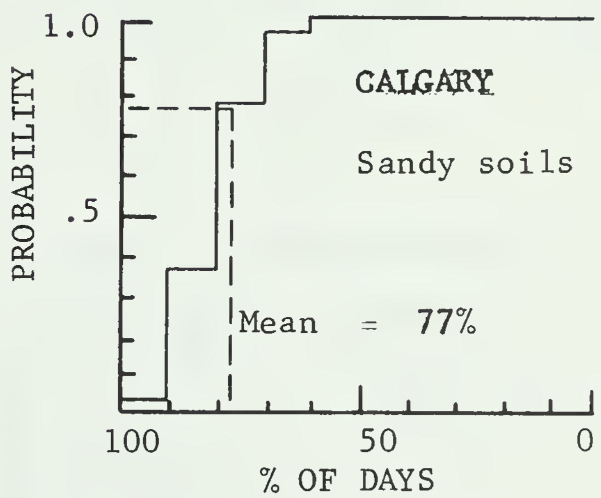

1.0
.5
PROBABILITY
EDMONTON
Medium to heavy soils
Mean = 69%
100
50
0
% OF DAYS

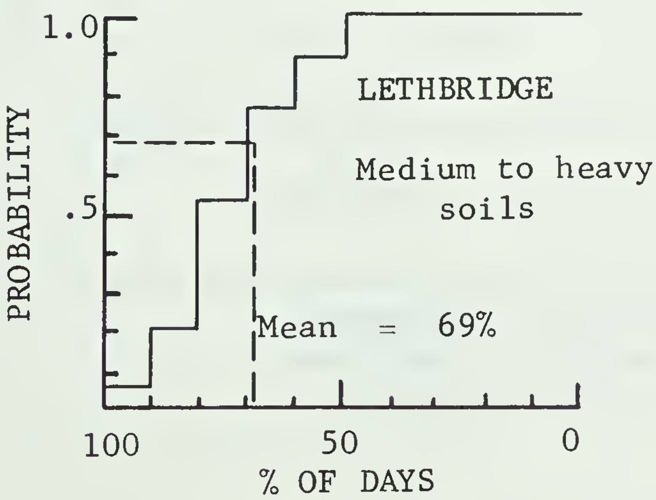

1.0
.5
PROBABILITY
EDMONTON
Sandy soils
Mean = 81%
100
50
0
% OF DAYS

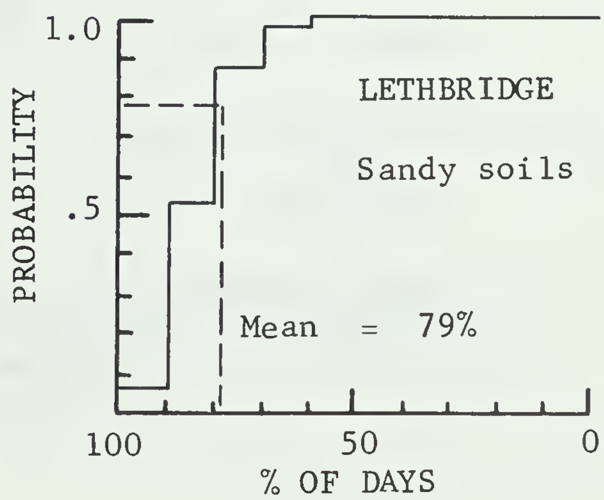

1.0
.5
PROBABILITY
VERMILION
Medium to heavy soils
Mean = 70%
100
50
0
% OF DAYS


1.0
.5
PROBABILITY
VERMILION
Sandy soils
Mean = 81%
100
50
0
% OF DAYS


1.0
.5
PROBABILITY
CALGARY
Medium to heavy soils
Mean = 65%
100
50
0
% OF DAYS


1.0
.5
PROBABILITY
CALGARY
Sandy soils
Mean = 77%
100
50
0
% OF DAYS


1.0
.5
PROBABILITY
LETHBRIDGE
Medium to heavy soils
Mean = 69%
100
50
0
% OF DAYS


1.0
.5
PROBABILITY
LETHBRIDGE
Sandy soils
Mean = 79%
100
50
0
% OF DAYS

Continued......

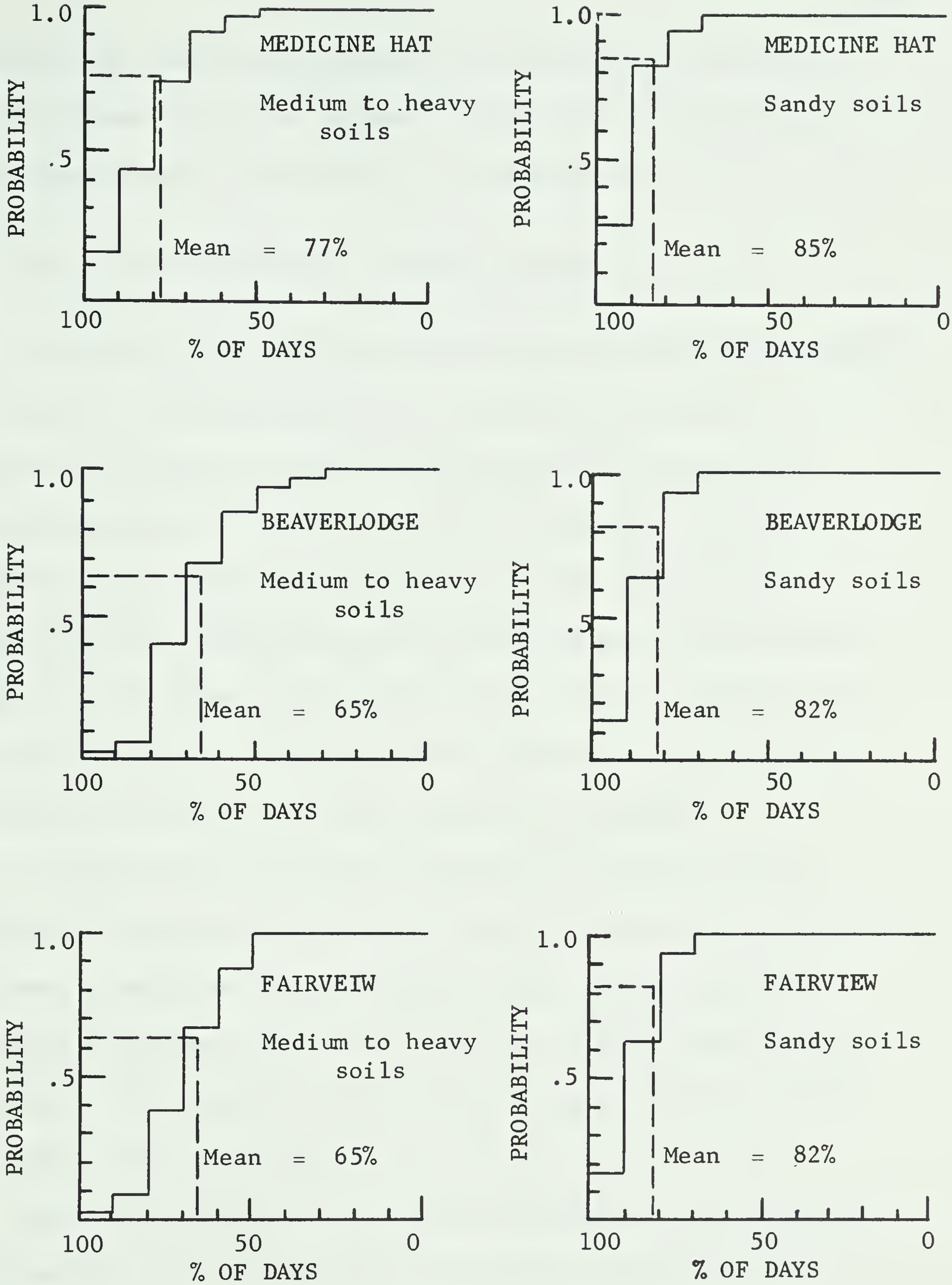


Figure 22. Cumulative probability of <u>at least a given percentage</u> of the total number of days being work days (for the period April 16 - June 15) for various regions and soils.

Medicine Hat whereas the probability of obtaining the mean is 65-77%, depending on the station. These results show that the mean expectation of work days is a good measure.

6.5 The Cost of Gambling on Favourable Weather

To complete the discussion of the sensitivity of gross margin to changes in machinery prices, it should be noted that in figure 11-21 there is a greater likelihood of realizing the optimum returns for deviations from the expected mean towards fewer work days than towards a greater number of work days. Figure 22 shows the probability in any one year of obtaining the returns represented by the curves of section 6.2. Figure 22 also shows that in some years, the returns could not be obtained because all of the crop acreage could not be seeded.

A useful bit of information would be a measure of the penalty one could expect in a year where the available time was the mean expectation of work days and the machinery available was that which was sized on the basis of a higher expectation of work days. This would in effect lower the part of the curve on the upper side of the mean.

Case study numbers 1, 2 and 4 were chosen for this analysis because they contained no haying activities in the solution. Then the linear programs which were set up for 100%, 80% and 60% of maximum time were run with tillage and seeding machinery limited to the sizes which were in the final solution of these

case studies (see section 6.2). Available times were set at the mean expected times used in determining the optimum machinery sizes (see section 5.2). These restrictions would in effect limit the amount of land which could be seeded.

Figure 23 shows the resulting gross margin curves for these three case studies. The curves show that having machinery which is too small may reduce returns to a greater extent than having machinery too large. However, the penalty for having machinery too small is only incurred in the years that the total available time for field operations is less than the time required for the size of machinery used by the operator. The cost of using large machinery is incurred every year. Therefore the average penalty over several years would not likely be as high as indicated by the curves in figure 23. It could be greater or less. One can really not tell precisely where the curve should be because these solutions are based on a plan which is constructed before the season begins. An operator will probably change the plan in the light of the progress he makes throughout the season and will probably make out better in the face of adverse weather than the curves indicate. For example, if adverse weather prevents seeding the expected wheat acreage the operator may seed the remaining acreage in oats, barley, or greenfeed and accept a lower return but not a zero return. He may also resort to hiring labour and work a double shift or custom hire another machine and in this way complete his work.

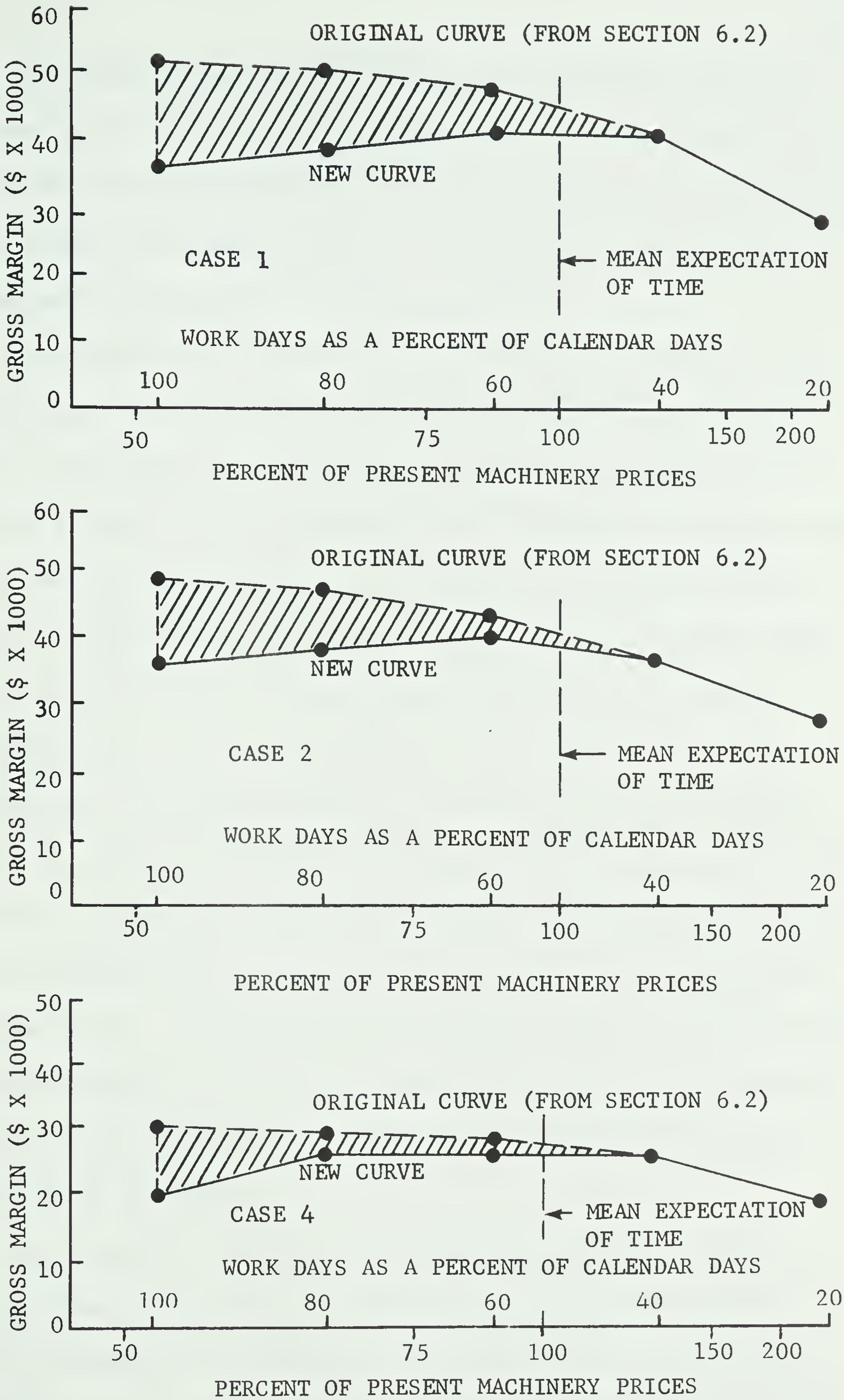


Figure 23. Graphs showing the gross margin resulting from undersizing machinery and gambling on favourable weather.

One may conclude that the curves will probably fall in the shaded areas of the graphs of figure 23. Purchasing machinery larger than the size calculated for the mean expected time is a predictable loss while purchasing machinery a little smaller is probably a good gamble, especially if short of capital.

One would expect that the new curve and the original curve would meet at the optimum gross margin. However, they do not due to the method in which the new curve was calculated. The points on the new curve at 60, 80 and 100 percent of maximum time were calculated by rerunning the same linear programs as were used for the original curve except that seeding machinery sizes were limited to the sizes which were in the solution for the original curve. Time was limited to the amount at the mean expectation. However, time was allocated between the sequence machines using the Lagrange multiplier technique (see section 5.1). The cost coefficient for the tractor had been changed from $16.7 per horsepower for the original curve to $21 per horsepower for the new curve. (Reasons for the change are given in section 6.1.) Also the original curve is the solution of the second run of the five time levels with cost coefficients improved according to table C2 of appendix C.

As a result of these cost coefficient changes the time allocations for the linear program runs for the new curve do not correspond to the machine size limitations. The solutions vindicated this fact because some of the implements did not enter

the solution to their limits. Also when solving the linear programs for the new curves the harvesting machinery was left to size itself on the basis of the time allocation of the programs solved for the original curve. For these reasons the two curves do not meet at the optimum gross margin.

7. RESUME OF CONCLUSIONS

The fixed and penalty (due to weather damage) costs of combining may be minimized by using a combine which will complete harvesting operations in ten to fourteen days. The cost per acre for a wheat farm at Edmonton is about $4.30 per acre. However, the penalty for using a combine which will complete harvest in more or less time than the 10 to 14 days is not high. Using a combine which will complete harvest quickly may be considered valuable insurance because a large percentage of the time there will be no penalty at all, and if there is a penalty it will be smaller than the penalty for completing harvesting more slowly.

Optimum machine sizes can be determined in relation to all of the activities on the farm. Including machinery has a bearing on the size of the various activities. A higher return may be obtained by including machinery costs in a mathematical model which selects farm activities than by either picking machinery subsequent to decisions regarding farm activities or considering existing machinery as a constraint on farm activities.

Generally, the machinery sizes on the farm are not close to the calculated optimum sizes. However, the size and type of the cropping activities which were on the farm were not the same as those which were in the solution of the mathematical programs, so the comparison is not very good. However, the comparison did

show that on many farms the relative sizes of seed drills and harrows are not large enough as compared to chisel plows and one-way diskers.

The average yearly machinery fixed costs are about $4.50 per acre for the eleven case studies which represents about 17% of the comparable gross margin. (The comparable gross margin is a term defined in section 5.1 as net income plus some fixed costs such as building depreciation and taxes.) Machinery fixed costs, then are significant costs in the farmer's budget but are not critical. A 10% oversizing of machinery will mean a 1.4% decrease in comparable gross margin.

The total returns on some farms decreased considerably as machinery prices increased but on other farms there was very little change. In general, there should be a shift away from cropping activities and toward animal enterprises as the price of machinery goes up or as the farmer is less inclined to gamble and therefore purchase large machinery. Purchasing machinery which is sized to handle the field crop operations in the mean expected time (as calculated from the work day probabilities from appendix G and the seasonal limits of appendix A) will probably yield the maximum gross margin. Purchasing larger machinery will ensure that the seeding operations can be completed at a predictable added cost. Purchasing smaller machinery may reduce total returns. However, if the operator can effectively adjust the cropping plan as the seeding season progresses the returns can

probably be kept at close to or possibly greater than the maximum returns obtained at the mean expected time. One may conclude that tillage and seeding machinery should be the size which will allow seeding to be completed in slightly more than the expected mean available time.

8. BIBLIOGRAPHY

1. Agricultural Machinery Administration Test Reports. Province of Saskatchewan Department of Agriculture. 1960-1965.

2. Anderson, A.W. "A Study of the Application of Linear Programming and the Associated Technique of Decomposition for Use on Farm Management Problems in Alberta." Unpublished M.Sc. Thesis, Department of Agricultural Engineering, University of Alberta, 1965.

3. Coates, W.E. Unpublished Computer Program written to assess penalty costs of combining. 1968. (Program listed in appendix F).

4. Domier, K.W. Personal interview with. Professor, Department of Agricultural Engineering, University of Manitoba, June 20, 1968.

5. Donaldson, G.F. "Allowing for Weather Risk in Assessing Harvest Machinery Capacity" American Journal of Agricultural Economics, Vol. 50 (1), 1968, 24-40

6. Donaldson, G.F. and Webster, J.P.G. "A Simulation Approach to the Selection and Combination of Farm Enterprises" The Farm Economist, Vol. XI (6), 1967.

7. Frisby, James G. and Bockhop , C.W. "Influence of Weather and Economics on Corn Harvesting Machinery Systems", Paper no. MC - 66 - 306 for presentation at the 1966 Annual Meeting, Mid-Central Section, American Society of Agricultural Engineers, St. Joseph, Missouri, March 25-26.

8. ______________"General Purpose Simulation System/360 User's Manual". IBM Application Program No. H 20-0326-2, 1968.

9. Hunt, Donnell R. "Efficient Field Machinery Selection", Agricultural Engineering, Vol. 44 (February 1963), 78-79 and 88.

10. Link D.A. "A Method for Predicting the Capabilities of a System of Farm Field Machinery Operating under Realistic Weather and Crop Conditions", Commission Internationale de Genie Rural, VIth International Congress of Agricultural Engineering, Lausanne, Switzerland, Sept. 21-27, 1964, 1077-1085.

11. MacHardy, F.V. "A Method of Sizing Farm Machines for Weather Dependent Operations", Canadian Agricultural Engineering, Vol. 8 (1966), 26-28.

12. MacHardy, F.V. "An Investigation of the Application of Programming Techniques to Farm Management Problems". Unpublished Ph.D. Thesis, Faculty of Science, University of Edinburgh, 1964.

13. MacHardy, F.V. "Product Terms in Mathematical Programming", Canadian Agricultural Engineering, Vol. 10 (1968), 51-52 and 56.

14. MácHardy, F.V. "Programming for Minimum - Cost Machinery Combinations", Canadian Agricultural Engineering, Vol. 8 (1966), 22-25.

15. ______________ "Mathematical Programming System/360 (360A - CO - 14X) Linear and Separable Programming - User's Manual", IBM Application Program No. H 20-0476-0, 1967.

16. ______________ "The Nebraska Tractor Tests". Annual publications of the Agricultural Experimental Station, University of Nebraska College of Agriculture and Home Economics, 1950-1965.

17. ______________ "1967 Agricultural Engineers' Yearbook". American Society of Agricultural Engineers, 252-254.

18. Preston, T.A. "A Computer Programme for the Evaluation of Alternative Methods", Canadian Agricultural Engineering, Vol. 9 (July 1967), 109-112.

19. Rutledge, P.L. "The Influence of the Weather on Field Tractability in Alberta". Unpublished M.Sc. Thesis, Department of Agricultural Engineering, University of Alberta, 1968.

20. Rutledge, P.L. and MacHardy, F.V. "The Influence of Weather on Field Tractability", Canadian Agricultural Engineering, Vol. 10 (November 1968), 70-73.

21. Soil Survey Reports, Published by the Alberta Soil Survey, University of Alberta. Report No. 19 Rocky Mountain House Sheet, Report No. 15 Rycroft and Watino Sheets (1950), Report No. 16 Red Deer Sheet (1951), Report No. 17 High Prairie and McLennan Sheets (1952), and the Blackfoot and Calgary Sheets (1960).

22. Sowell, R.S. and Link, D.A. "Dynamic Programming Formulation of the Machinery Replacement Problem with Application to the Replacement of Cotton Picker". Paper no. 67-616 for presentation at the 1967 Winter Meeting, American Society of Agricultural Engineers, Detroit, Michigan, December 12-15.

23. Stapleton, H.N. "Analyzing Field Machinery Systems by Computer", Agricultural Engineering, April, 1967, 202, 203 and 225.

APPENDICES

APPENDIX A

FIELD CROP OPERATION TIME PERIODS

1. Information Retrieval Methods

Outside time limits for field operations for the crops which are grown in the various districts of the Province were established by personal interviews with the district agriculturists. The results of these interviews are contained in the following sections.

The district agriculturists also gave an opinion on which weather station record used by Rutledge (19) was most like that of the particular area.

2. Vulcan - Arrowwood

District Agriculturist: Mr. Blair Shaw

Weather (for Arrowwood region): similar to Calgary

Field crop limits (for Arrowwood):

Field cultivation begins April 8
Spraying is done in June
Fallow - start April 30 and do several times during summer

TABLE A1. FIELD CROP OPERATION TIME PERIODS - ARROWWOOD

Crop	Seeding	Begin harvesting
Spring wheat	April 30 - May 21	August 8
Oats	May 1 - June 21	August 21
Barley	May 1 - June 21	August 8
Rye - on fallow	August 15 and on	July 25 - August 8
Rye - on stubble	September 15 and on	July 25 - August 8
Flax	May 10 - June 18	August 18
Rape seed	May 8 - June 1	August 20
Mustard	May 1 - June 20	August 21
Yellow mustard	May 1 - June 20	August 8
Cover crop	August 1 - 15	-
Hay - 1st cut	-	July 2 - 20
Hay - 2nd cut	-	August 20

3. Olds

District Agriculturist: Mr. Larry Welsh

Weather: similar to Edmonton

Field crop limits:

Field cultivation begins May 1
Spraying is done in June
Fallow - cultivated once or twice in June and 4 times in July, August and September

TABLE A2. FIELD CROP OPERATION TIME PERIODS - OLDS

Crop	Seeding	Begin harvesting
Spring wheat	May 9 - 30	September 3
Oats	May 10 - June 4	September 3
Barley	May 17 - June 15	August 27
Rye	September 1 - 15	August 15 - Sept. 15
Flax	May 15 - 25	September 23
Rape seed	May 20 - June 10	August 24
Greenfeed	June 24 - July 5	August 25 - Sept. 10
Hay - 1st cut	-	July 1 - 25
Hay - 2nd cut	-	Sept. 5 - 30

4. Red Deer

District Agriculturist: Mr. R.D. Price

Weather: similar to Edmonton

Field crop limits:

Field cultivation begins May 1
Spraying is done in June
Fallow - cultivated once or twice in June, and 4 times in July, August and September

TABLE A3. FIELD CROP OPERATION TIME PERIODS - RED DEER

Crop	Seeding	Begin harvesting
Spring wheat	May 15 - 25	September 1
Oats	May 15 - 25	September 1
Barley	May 15 - 30	August 15
Rye	September 1 - 20	August 15
Rape seed	June 1 - 15	August 25
Greenfeed	June 15 - 30	August 15
Hay - 1st cut	-	June 20 - July 15
Hay - 2nd cut	-	August 15 - Sept. 18

5. Athabaska

District Agriculturist: Mr. G.L. Godel (now in Edmonton)

Weather: similar to Beaverlodge

Field crop limits:

Field cultivation begins May 10
Spraying is done in June
Fallow - very little fallow land

TABLE A4. FIELD CROP OPERATION TIME PERIODS - ATHABASKA

Crop	Seeding	Begin harvesting
Spring wheat	May 10 - 15	September 1
Oats	May 10 - 25	September 1
Barley	May 10 - June 10	August 25
Rye	August 20 - Sept. 1	August 1
Flax	May 25 - June 10	September 1
Rape seed	May 25 - June 10	August 25
Hay - 1st cut	-	June 25
Hay - 2nd cut	-	August 10

6. High Prairie

District Agriculturist: Mr. T.T. Newcombe

Weather: similar to Beaverlodge

Field crop limits:

Field cultivation begins May 7
Spraying is done June 15 - July 10
Fallow - cultivated after June 15

TABLE A5. FIELD CROP OPERATION TIME PERIODS - HIGH PRAIRIE

Crop	Seeding	Begin harvesting
Spring wheat	May 7 - 24	September 10
Oats	May 15 - June 6	September 1
Barley	May 15 - June 10	August 25
Flax	May 25 - June 1	October 15
Rape seed	May 25 - June 1	September 10
Greenfeed	June 1 - 20	-
Hay	-	July 10 - August 15

7. Spirit River

District Agriculturist: Mr. D. Dowswell

Weather: similar to Fairview

Field crop limits:

Field cultivation begins May 1
Spraying is started about June 15
Fallow - started in late June and done 4 or 5 times

TABLE A6. FIELD CROP OPERATION TIME PERIODS - SPIRIT RIVER

Crop	Seeding	Begin harvesting
Spring wheat	May 1 - 15	September 1
Oats	May 1 - 30	September 10
Barley	May 1 - June 20	August 10
Flax	May 1 - June 1	September 15
Rape seed	May 1 - June 20	August 15
Greenfeed	May 1 - July 1	August 25
Hay - 1st cut	-	June 25
Hay - 2nd cut	-	August 15

APPENDIX B

HORSEPOWER REQUIREMENTS FOR FIELD MACHINERY

Horsepower requirements per unit capacity for tillage machinery will vary considerably depending on factors such as land topography and soil type, moisture content, and density. For harvesting machinery, horsepower requirements depend on factors such as crop type and condition, and rolling resistance of the machine in the field.

Two sources of data are available to aid in estimating these requirements. The Agricultural Machinery Administration (AMA) reports (1) give some information for Saskatchewan conditions. The 1967 ASAE Yearbook (17) lists draft requirements, efficiency estimates, and rated ground speeds for various machines from which horsepower requirements can be obtained.

The following sections contain estimates of horsepower requirements based on information from these two sources. Only machines that were expected to load the tractor are included.

A formula for obtaining capacity in acres/hour from machine width, ground speed and an efficiency factor is given in the 1967 ASAE Yearbook (17). The formula is as follows:

$$C = \frac{S\ W\ E}{825} \tag{A1}$$

where C = capacity in ac/hr
S = speed in mph
W = width in feet
E = efficiency in percentage

Another formula relating draw bar horsepower to draft and ground speed was obtained from the 1967 ASAE Yearbook (17) and is as follows:

$$dbHP = \frac{D\ S}{375} \qquad (A2)$$

where dbHP = draw bar horsepower
D = draft (lb/foot width)
S = speed (mph)

3.1 Horsepower Requirements for Chisel Plows

Sources: AMA Test Reports

1967 ASAE Yearbook

TABLE B1. CHISEL PLOW POWER REQUIREMENTS FOR VARIOUS MODELS

AMA Test report no.	Make	Width	dbHP*	dbHP/ft.
364 (1965)	MF 124	15'	70	4.60
264 (1965)	ROBIN RC12	16'	65	4.06
164 (1964)	IHC 55	20'	82	4.10
663 (1964)	JD 120F	22'	92	4.18
563 (1964)	GRAHAM BHW - 22	22'	85	3.86
762 (1963)	COCKSHUTT 247	14'	59	4.21
562 (1963)	MM T506	14'	69	4.93
559 (1960)	JD 114	14'	43	3.07
459 (1960)	CASE CP15S	15'	42	2.80
			TOTAL	35.81
			AVERAGE	3.98

* at 4" depth and 4.5 mph

Efficiency estimate 82.5%

$$C = \frac{S\ W\ E}{825} = \frac{4.5 \times 1 \times 82.5}{825} = 0.45 \text{ ac/hr}$$

$$\text{Horsepower required} = \frac{3.98}{0.45} = 8.9 \text{ HP/ac/hr.}$$

3.2 Horsepower Requirements for One-Way Disk Tillers with Seeding Attachment

TABLE B2. ONE WAY DISK POWER REQUIREMENTS FOR VARIOUS MODELS

AMA Test report no.	Make and model	Width*	dbHP**	dbHP/ft.
262 (1962)	JD 1700	16'	27	1.69
261 (1962)	IHC 100	15'	35	2.33
362 (1962)	MF 36	18'	37	2.06
163 (1964)	COCKSHUTT 225	15'	37	2.47
			TOTAL	8.55
			AVERAGE	2.14

* Width is width of cultivation

** dbHP at 3" depth and 4.5 mph in clay loam soil.

Efficiency estimate 70%

$$C = \frac{S\ W\ E}{825} = \frac{4.5 \times 1 \times 70}{825} = 0.38 \text{ ac/hr}$$

$$\text{Horsepower required} = \frac{2.14}{0.38} = 5.6 \text{ HP/ac/hr}$$

3.3 Horsepower Required for Double Disker (light duty)

Source: 1967 ASAE Yearbook p. 253

Estimates: Draft - 140 lb/ft
Speed - 4.5 mph
Efficiency - 82.5%

$$dbHP = \frac{D\ S}{375} = \frac{140 \times 4.5}{375} = 1.68 \text{ HP/ft}$$

$$C = \frac{S\ W\ E}{825} = \frac{4.5 \times 1 \times 82.5}{825} = 0.45 \text{ ac/hr/ft}$$

$$\text{Horsepower required} = \frac{1.68}{0.45} = 3.73 \text{ HP/ac/hr}$$

3.4 Horsepower Required for a Seed Drill

Source: 1967 ASAE Yearbook p. 253

Estimates: Draft - 60 lb/ft

Speed - 4.5 mph

Efficiency - 70%

$$dbHP = \frac{D\ S}{375} = \frac{60 \times 4.5}{375} = 0.72 \text{ HP/ft}$$

$$C = \frac{S\ W\ E}{825} = \frac{4.5 \times 1 \times 70}{825} = 0.382 \text{ ac/hr/ft}$$

$$\text{Horsepower required} = \frac{0.72}{0.38} = 1.9 \text{ HP/ac/hr}$$

3.5 Horsepower Required for Spike Tooth Harrows

Source: 1967 ASAE Yearbook p. 253

Estimates: Draft - 50 lb/ft

Speed - 5 mph

Efficiency - 80%

$$dbHP = \frac{D\ S}{375} = \frac{50 \times 5}{375} = 0.67 \text{ HP/ft}$$

$$C = \frac{S\ W\ E}{825} = \frac{5 \times 1 \times 80}{825} = 0.485 \text{ ac/hr/ft}$$

$$\text{Horsepower required} = \frac{0.666}{.485} = 1.4 \text{ HP/ac/hr}$$

3.6 Horsepower Required for Rod Weeders (pull type)

Source: 1967 ASAE Yearbook p. 253

Estimates: Draft - 90 lb/ft

Speed - 4.5 mph

Efficiency - 82.5%

$$\text{dbHP} = \frac{D\ S}{375} = \frac{90 \times 4.5}{375} = 1.08 \text{ HP/ft}$$

$$C = \frac{S\ W\ E}{825} = \frac{4.5 \times 1 \times 82.5}{825} = 0.45 \text{ ac/hr/ft}$$

$$\text{Horsepower required} = \frac{1.08}{0.45} = 2.4 \text{ HP/ac/hr}$$

3.7 Horsepower Required for Parkers

For purposes of programming, it was assumed that the horsepower for parkers was the same as for rod weeders.

3.8 Horsepower Required for Forage Harvesters

Source: 1968 ASAE Yearbook, p. 253

Field chopper: Grass silage, 1/2 inch theoretical cut requires 1 - 2.5 HP/ton/hr

Assumed requirement 2.5 HP per ton/hr capacity

Note: Since this is PTO HP, it will be an over estimation when dealing with draw bar horsepower.

3.9 Summary of Horsepower Requirements

TABLE B3. SUMMARY OF HORSEPOWER REQUIREMENTS FOR FIELD MACHINERY

Machine type	Draw bar horsepower required (per ac/hr or ton/hr capacity)
Chisel plow	8.9
One-way disk tiller	5.6
Double disker (light duty)	3.7
Seed drill	1.9
Spike tooth harrow	1.4
Rod weeder	2.4
Packer	2.4 (assumed)
Forage harvester	2.5 (PTO)

APPENDIX C

FIXED COST CURVES FOR FIELD MACHINERY

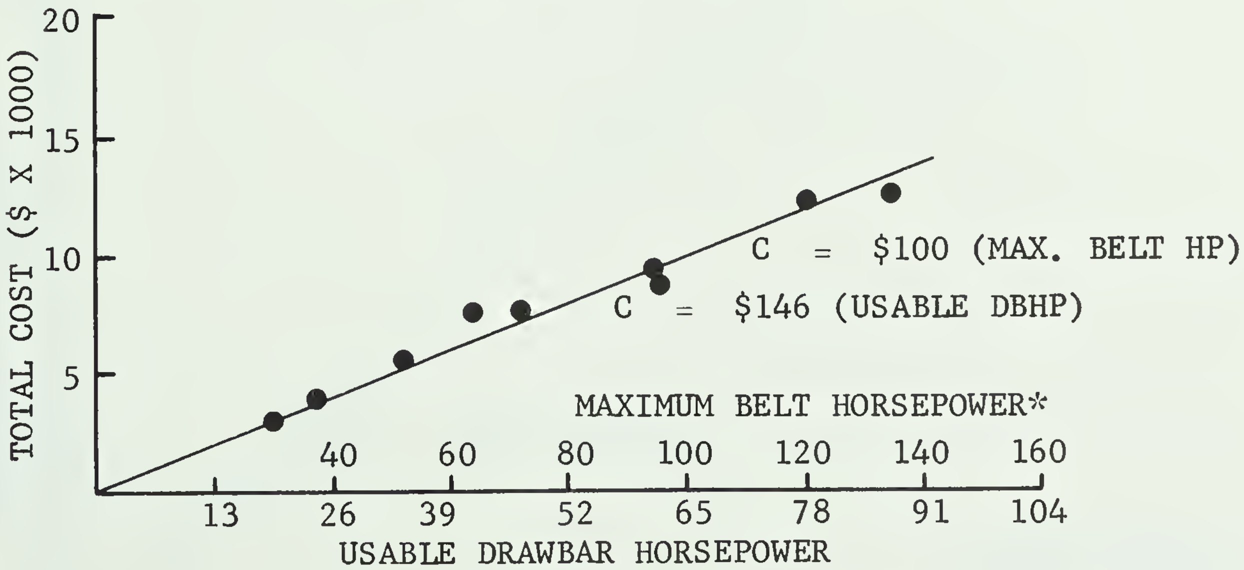
1. Sources of Data and Method of Presentation

The cost of machinery per unit capacity was established by collecting data from a number of dealers. The machines were equipped with approximately the same extras required to perform the job intended. The prices used are for the year 1967. The data was plotted as shown in the following graphs. Linear approximations to the data were made for programming purposes. Machinery capacity was estimated using the relationship

$$C = \frac{S\ W\ E}{825} \quad \text{....................(C1)}$$

where C = capacity (ac/hr)
S = speed (mph)
W = width (feet)
E = efficiency (%)

2. Tractors (Two Wheel Drive)



* obtained from Nebraska Tractor Tests (16)
** Domier (4) suggested that 55-75% of maximum belt horsepower is available at the drawbar. The graph is based on 65%.

Figure C1. Tractor total fixed cost curve.

3. Chisel Plow

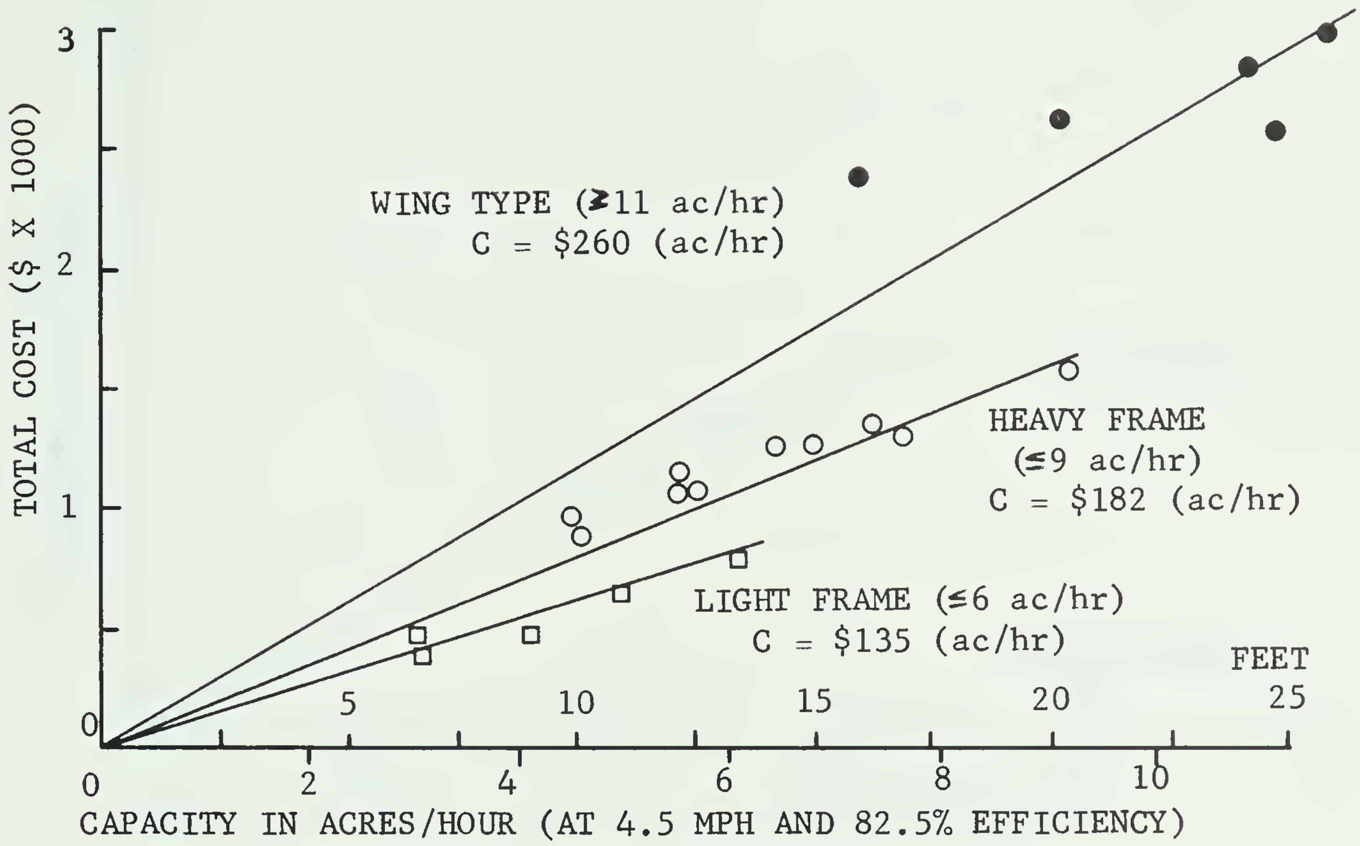


Figure C2. Chisel plow total fixed cost curves.

4. One-way Disker (With Grain and Fertilizer Boxes)

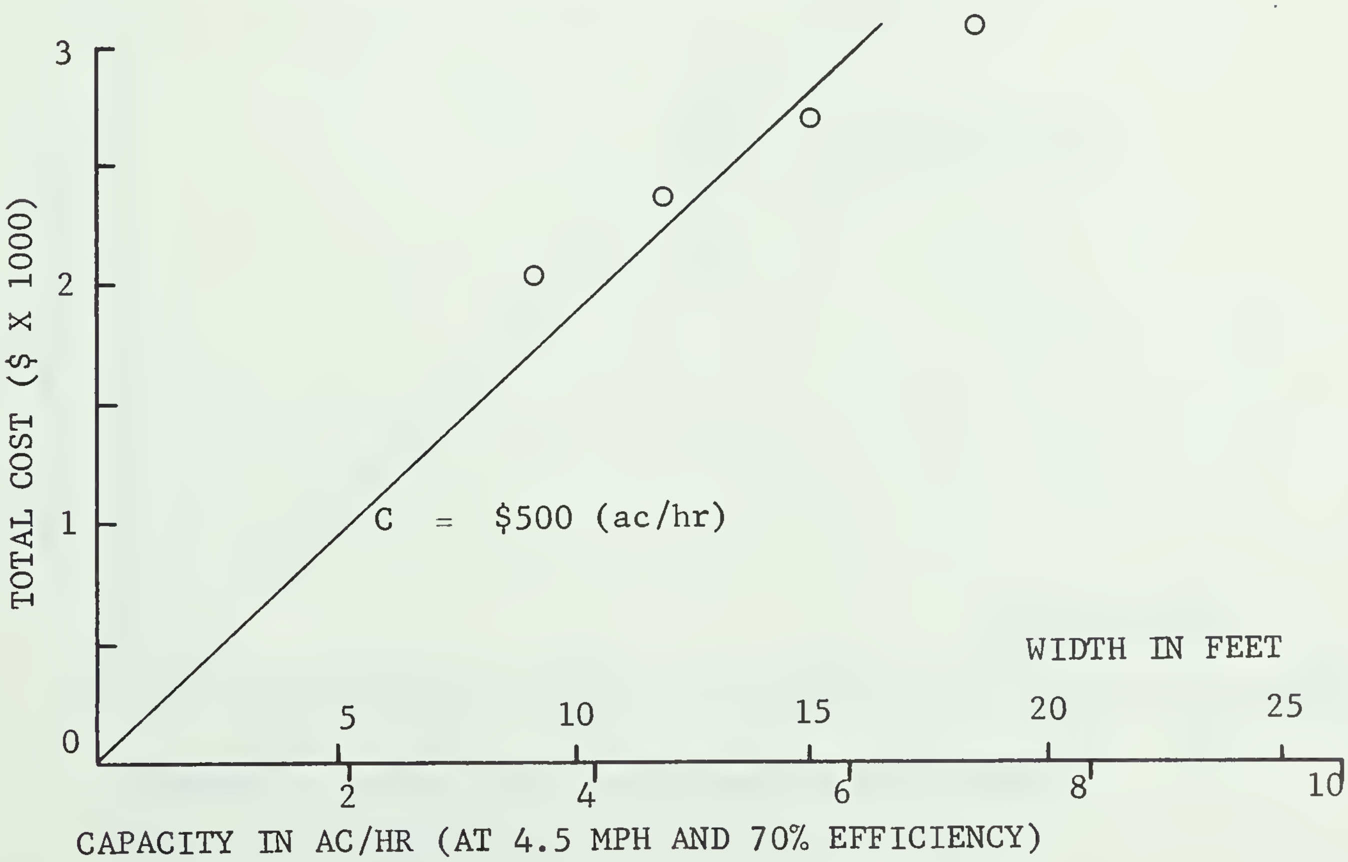


Figure C3. One-way disker total fixed cost curve.

5. Double Disk

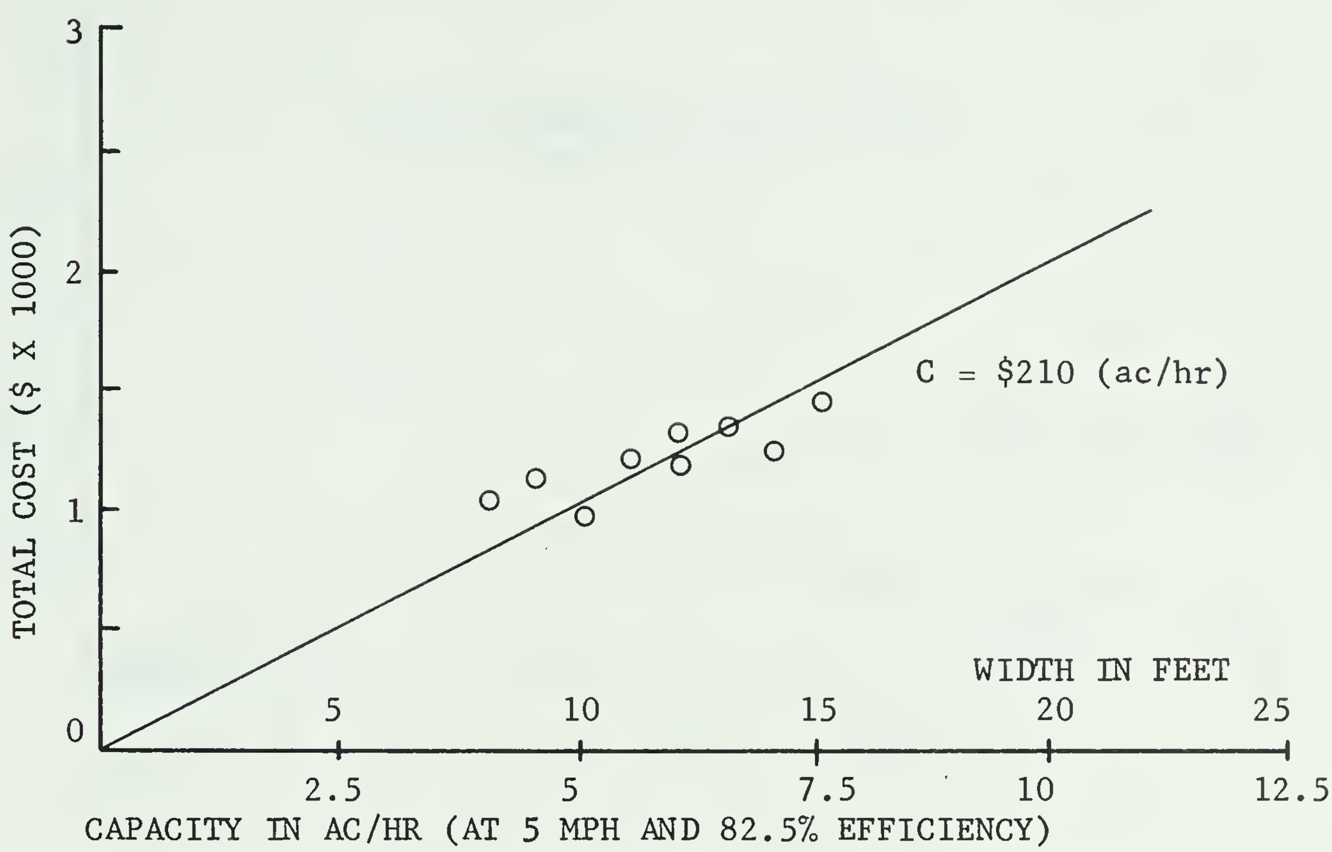


Figure C4. Double disk total fixed cost curve.

6. Seed Drill (With Fertilizer and Grass Seed Attachments)

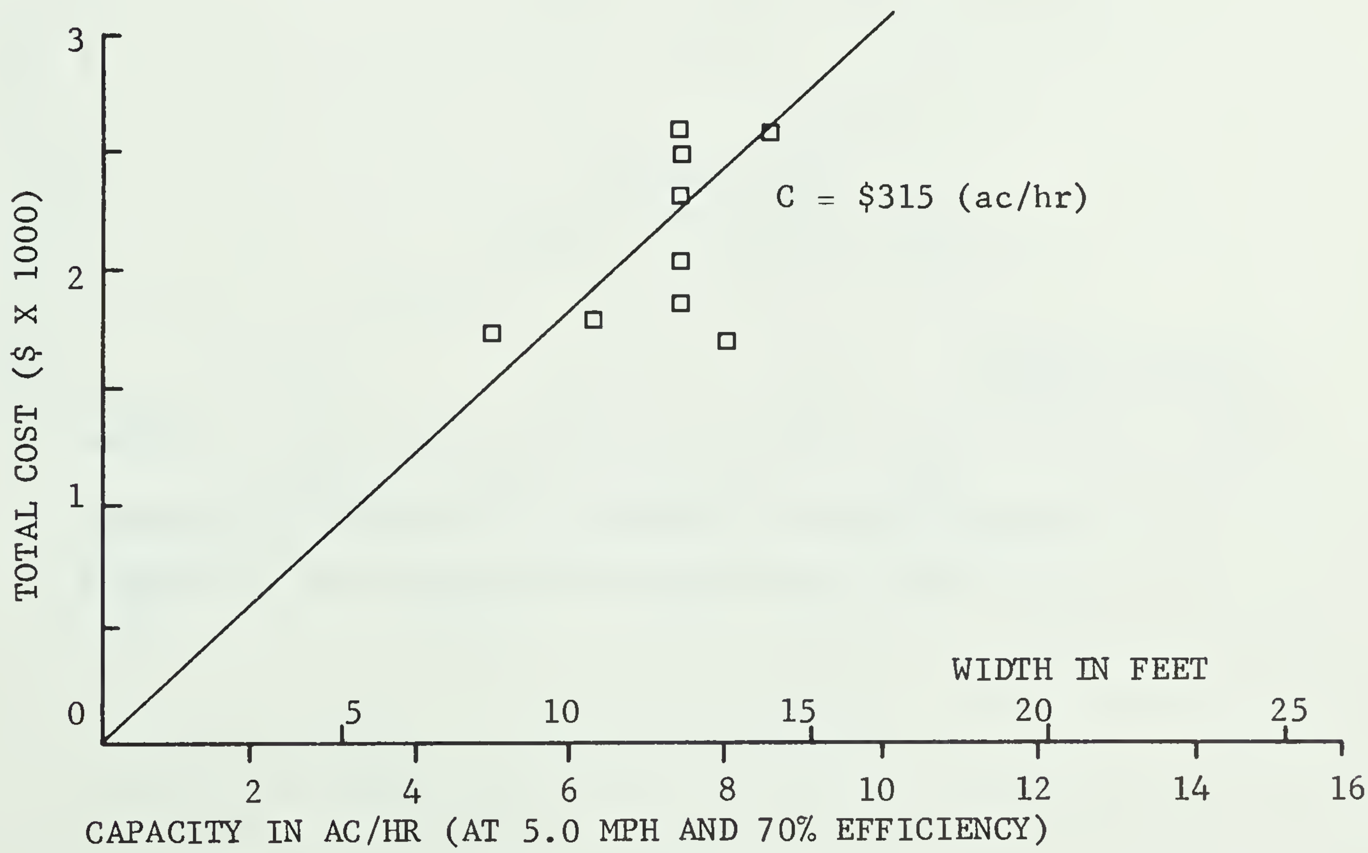


Figure C5. Seed drill total fixed cost curve.

7. Spike Tooth Harrows

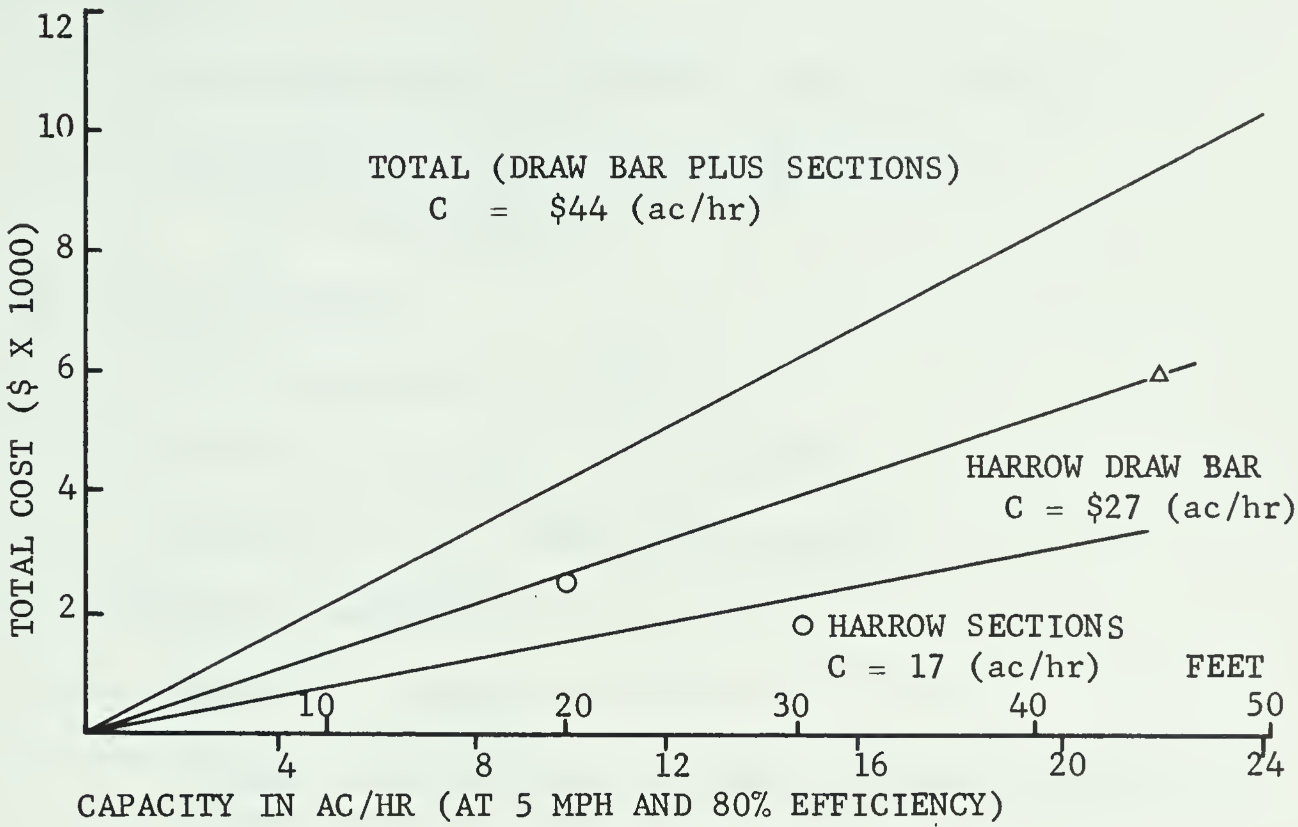


Figure C6. Spike tooth harrows total fixed cost curves.

8. Rod Weeder

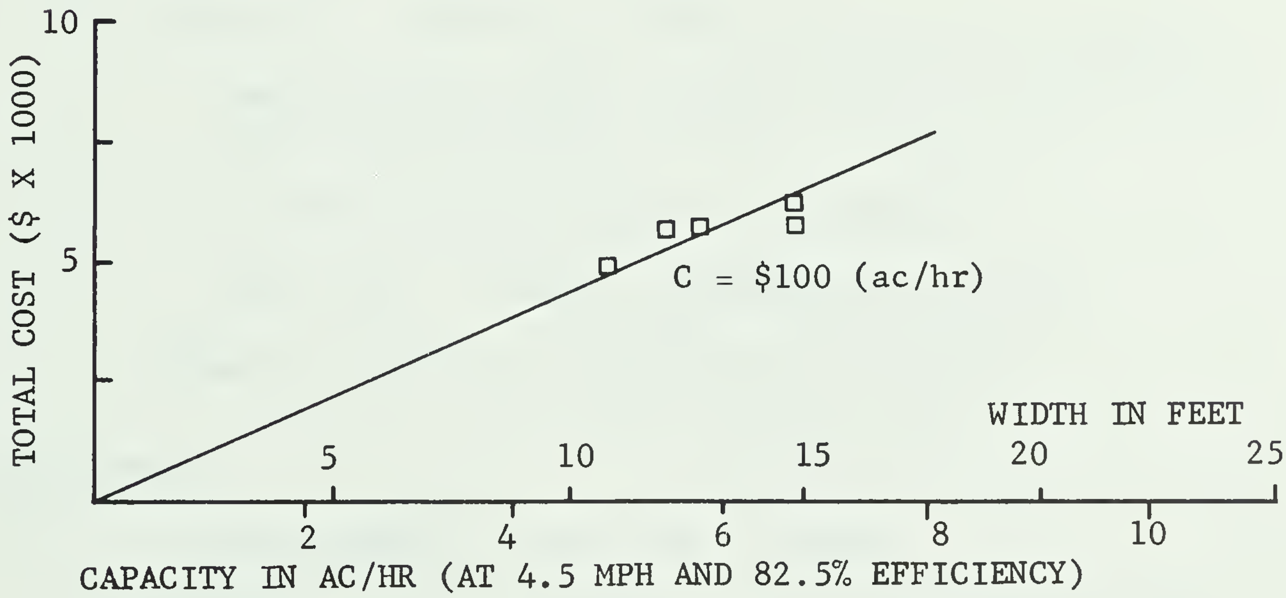


Figure C7. Rod weeder total fixed cost curve.

9. Packers

Total fixed cost = \$200/4' length or \$50/foot

Assuming the same capacity as rod weeders,

C = \$110/ac/hr

10. Forage Harvester

Total fixed cost = \$3750

Estimated capacity = 12.5 ton/hr

Therefore C = \$300/ton/hr capacity

11. Self-Unloading Wagon

Wagon #1: capacity of 4 tons

Time to haul (1 mile each way) load and unload is 23 minutes (estimated)

At 80% efficiency that is 8.3 ton/hr.

Total cost = \$1838 or \$220/ton/hour capacity.

Wagon #2: capacity of 5 tons

Time to haul (1 mile each way) load and unload is 25 minutes (estimated)

At 80% efficiency that is 9.6 ton/hour.

Total cost = \$2037 or \$209/ac/hr capacity.

Therefore set cost at \$210/ton/hour capacity.

12. Mower

7 foot machine - total cost = \$725

$$\text{Capacity} = \frac{S\ W\ E}{825} = 3.15 \qquad \text{where } S = 4.5 \text{ mph},\ W = 7,\ E = 82.5$$

$$\text{Cost} = \frac{725}{3.15} = \$230/\text{ac/hr capacity}$$

13. Rake

7 foot machine - total cost \$700

Assume same capacity as mower = 3.15 ac/hr.

Cost = $\frac{700}{315}$ = \$222/ac/hr.

14. Baler (pull type)

Assumed capacity = 3.5 ton/hr.

Total cost = \$2300

Cost $\frac{2300}{3.5}$ = \$660/ton/hour/capacity

15. Self Propelled Swather

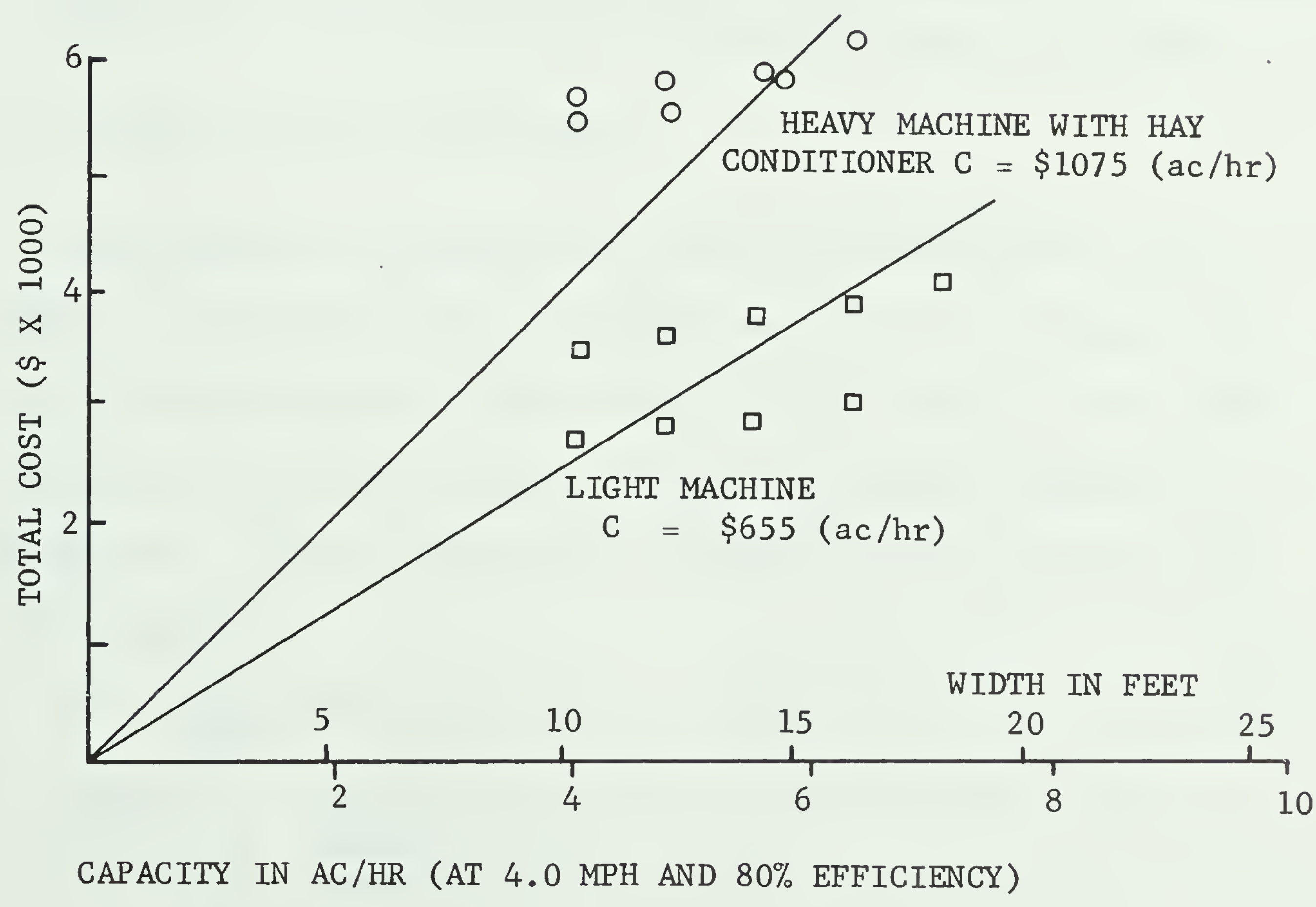


Figure C8. Self propelled swathers total fixed cost curve.

16. Self Propelled Combines (With Pickup Attachment)

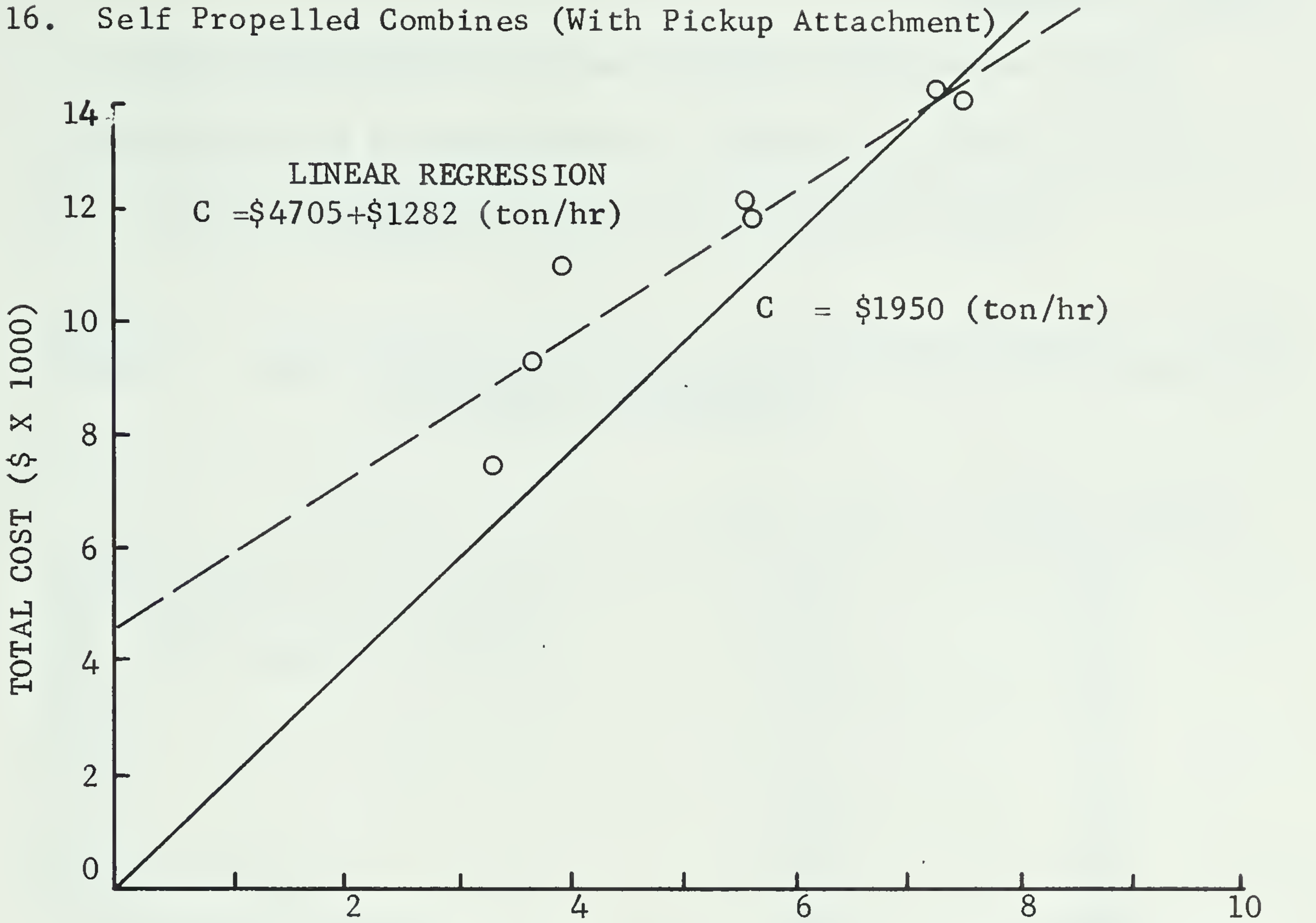


Figure C9. Self propelled combines total fixed cost curve.

17. Summary of Cost Coefficients

For machine sizes larger than the range of machinery on the market, it was assumed that an operator would have to be hired and that the machine cost per unit capacity would increase at the same rate as the cost of the largest machine. Labour was charged at \$2.50/hour. Thus the formula for calculating the machine cost per unit capacity is:

$$C = \frac{2.50}{P} DT + C_o \ldots\ldots\ldots\ldots\ldots\ldots (C2)$$

Where P = capacity of largest available machine (ac/hr, ton/hr)

C_o = cost/unit capacity at P

D = number of years in the life of the machine

T = hours of use per year

Total fixed costs for some machines which do not change significantly in price as capacity changes are given in table C1. The costs per unit capacity are given in table C2.

TABLE C1. TOTAL FIXED COSTS OF SOME MACHINES FOR WHICH PRICE DOES NOT VARY SIGNIFICANTLY

Machine	Total cost	Total cost/yr (7 yrs)
Grain self propelled swather	\$3500	\$500
Hay self propelled swather	\$5000	\$710
Mower	\$ 700	\$100
Rake	\$ 700	\$100
Baler	\$2300	\$330
Forage harvester	\$3600	\$520
Self unloading wagon	\$2000	\$285
Wagon	\$ 250	\$ 35

TABLE C2. SUMMARY OF MACHINERY COST COEFFICIENTS

Machine	Capacity	Cost per unit capacity (\$)	Cost per yr. for 7 years (\$)
Tractor	100 (dbHP)	146	21
Chisel plows	<9 (ac/hr)	182 (heavy duty)	26.0
	<9 (ac/hr)	135 (light duty)	19.3
	9-11 (ac/hr)	260 (wing type)	37.2
	11-18 (ac/hr)	210 (multiple hookup)	30.0
	>18 (ac/hr)	.139DT* + 210	-
Double disk	<10 (ac/hr)	210	30.0
	10-20 (ac/hr)	235 (multiple hookup)	33.6
		.125DT + 235	-

TABLE C2. CONTINUED

One-way disk harrows (grain & fert. box)	<7 (ac/hr)	500	71.5
	7-14 (ac/hr)	500 (multiple hookup)	71.5
	>14 (ac/hr)	.178DT + 500	-
Seed drills	<5.5 (ac/hr)	315	45.0
	5.5-11 (ac/hr)	360 (multiple hookup)	51.5
	>11 (ac/hr)	.227DT + 360	-
Spike tooth	<22 (ac/hr)	44.[illegible]	6.4
Harrows	≥22 (ac/hr)	.114DT + 44.	-
Packers		$110/ac/hr (assumed)	15.7
Rod weeder	<7 (ac/hr)	100	14.3
	7-14 (ac/hr)	135 (multiple hookup)	19.3
	>14 (ac/hr)	.179DT + 135	-
Mower	≤3 (ac/hr)	230	32.9
	>3 (ac/hr)	.83DT + 230	-
Rake	<3 (ac/hr)	222	31.8
	>3 (ac/hr)	.83DT + 222	-
Baler	<3.5(ton/hr)	$660	94.3
	>3.5(ton/hr)	.714DT + 660	-
Forage harvester	<12.5(ton/hr)	300	42.9
	>12.5(ton/hr)	.2DT + 300	-
Self unloading Forage wagons	<9(ton/hr)	210	30.0
	>9(ton/hr)	.278DT + 210	-
SP swather for hay (with conditioner)	<6(ac/hr)	1075	153.5
	>6(ac/hr)	.417DT + 1075	-
SP swather for grain	<7(ac/hr)	655	93.5
	>7(ac/hr)	.357DT + 655	-
SP combines	<5.5(ac/hr)	2690	384
	>5.5 (ac/hr)	.455DT + 2690	

* D = life of machine in years (e.g. 7 years)

T = hours use per year

APPENDIX D

LAGRANGE MULTIPLIER COMPUTER PROGRAM

The computer program contained in this appendix was written to calculate the solution to the Lagrange multipliers (14). The computer program will consider up to six sequence machines (including the tractor) and share the designated time between them according to the minimum cost solution. The method is to calculate the solution with the tractor being loaded by all machines, then all possibilities of one machine loading the tractor, two machines loading the tractor and so on until all combinations have been tried. The program begins by storing the first solution. Then, as each combination is calculated, it is tested to see if it is valid and better than the solution stored. If it is not an improvement over the one being stored an appropriate message is printed and the next combination is tried. If it is an improvement, it replaces the one stored. Finally the best solution is printed. The program will also punch out the solution according to the format required for input to the IBM 360 Linear and Separable Programming (15) format.

The program will also calculate the solution for 80%, 60%, 40% and 20% of the original time for all combinations of loading the tractor, and output the best solutions.

The first card of each run contains the number of problems (NUM) and an indicator (INDTR) to specify if the solution should

be calculated for all percentages of the original time. Figure D1 specifies the card data input necessary for each problem. Table D1 lists the input identification for figure D1.

TABLE D1. DESCRIPTION OF INPUT VARIABLES FOR THE LAGRANGE MULTIPLIER PROGRAM

Variable	Description
NUM =	Number of problems (an integer in columns 6-9, right justified)
INDIR =	1 if only 100% of time wanted (an integer in column 12)
LABEL =	Machinery names
CA =	Case number
N =	Number of machines (including the tractor)
T =	Time in hours
IND =	1 if no card output wanted b if card output wanted
HP =	Horsepower requirement per unit capacity
DEP =	Number of years over which machine is to be depreciated (linear depreciation)
C =	Total cost per unit capacity
A =	Acres or tons to be handled by the machine within the time period, each year).

The following pages contain a listing of the Lagrange Multiplier Program written in the FORTRAN IV computer language, and data for two problems.

DATA CARD FORMAT FOR LAGRANGE MULTIPLIER PROGRAM

Program # __________

Run # ______________

Note: The first card in each computer run must be the number of runs (col. 6-9) and INDTR (col. 12)

N or Field Number =	1	2	3	4	5	6
Column Numbers	7-12	13-18	19-24	25-30	31-36	37-42

Machinery names: Use the first four columns of each field. (A4 format)
(col. 7-10 must be the tractor)

(I2, I2, F6.1, I1, format)

Case #, N, Time, Indicator

Horsepower: (F6.1 format)

Life of machine (years)
(F6.1 format)

Series of COST and ACREAGE values for 5 time percentages (F6.1 format)

C = Total cost
(per ac/hr,
ton/hr)

A = Acreage values
(ac,tons)

Note: If INDTR = 1 fill out only 100% time cards.

100% Time C
A

80% Time C
A

60% Time C
A

40% Time C
A

20% Time C
A

Card output names: column obj. row row (2A4 format)

Machine number
(N-1 cards)

2
3
4
5
6

Figure D1. Data card format for Lagrange multiplier program.

```
C           LAGRANGE MULTIPLIER PROGRAM
C
      REAL C(12),A(12),HP(12),T,TIME(12),HR,B(12),D(12),X(12),Y(12),G,
     1SUM,ALT,TIMVAL(5,12),DEP(12),COST(12),STIMV(5),ERROR,PERC(5),ZS(5)
     2,TTIM(5),LABEL(12)
      INTEGER F,CA
200   FORMAT  (1X,2HZ=,F10.1,3X,9HY VALUES=,12F8.1)
201   FORMAT (1X,I4,8H%(TIME)=,F6.1,2X,4HHRS=,8X,11F8.1)
202   FORMAT (13X,12HHORSE POWER=,12F8.1)
114   FORMAT (1X,22HZ VALUE TOO LARGE    Z=,F10.3)
115   FORMAT (1X,17HHORSEPOWER FOR Y(,I2,14H) IS TOO LARGE)
109   FORMAT (1H0)
900   FORMAT ('1')
      READ (5,99) NUM,INDTR
99    FORMAT (6X,I3,2X,I1)
      DO 604 NT=1,NUM
      READ (5,105) LABEL
105   FORMAT (6X,12(A4,2X))
      READ (5,100) CA,N,T,IND
100   FORMAT (6X,I2,4X,I2,4X,F6.1,I1)
      READ (5,103)(HP(I), I=2,N)
103   FORMAT(12X,11F6.1)
      READ (5,103) (DEP(I),I=2,N)
      WRITE (6,160) CA,N,T
160   FORMAT (1H1,5HCASE ,I2,5X,20HNUMBER OF VARIABLES=,I2,5X,11HTOTAL T
     1IME=,F7.1,3HHRS)
      DO 51  IJ=1,5
      READ (5,101)(C(I), I=1,N)
101   FORMAT (6X,12F6.1)
      READ (5,102)(A(I), I=2,N)
102   FORMAT(12X,11F6.0)
      G=6-IJ
      F=20*(6-IJ)
```

```
      HR=G*0.2*T
      TTIM(IJ)=HR
      PERC(IJ)=F
C
C
C   WRITE CASE NO. AND INPUT VALUES
C
      WRITE (6,104) CA
104   FORMAT (1H0,5HCASE ,I2)
      WRITE (6,113) LABEL
113   FORMAT (23X,12(A4,4X))
      WRITE (6,110) (C(I),I=1,N)
110   FORMAT (1X,17HCOST COEFFICIENTS,12(2X,F6.1))
      WRITE (6,111) (A(I),I=2,N)
111   FORMAT (1X,8HA VALUES,17X,11(2X,F6.1))
      WRITE (6,112) (HP(I),I=2,N)
112   FORMAT (1X,17HHORSEPOWER VALUES,8X,11(2X,F6.1))
      WRITE (6,605) (DEP(I),I=2,N)
605   FORMAT (1X,19HDEPRECIATION VALUES,6X,11(2X,F6.1))
      ZS(IJ)=1000000.
      CALL        LOOP1 (CA,HP,C,A,HR,F,ALT,ZS,TIMVAL,IJ,LABEL,N)
      IF (N.LT.3) GOTO 50
      IF (C(1).LT.0.1) GOTO 50
      CALL        LOOPA (CA,HP,C,A,HR,F,ALT,ZS,TIMVAL,IJ,LABEL,N)
      IF (N.LT.4) GOTO 50
      CALL        LOOP2 (CA,HP,C,A,HR,F,ALT,ZS,TIMVAL,IJ,LABEL,N)
      IF (N.LT.5) GOTO 50
      CALL        LOOP3 (CA,HP,C,A,HR,F,ALT,ZS,TIMVAL,IJ,LABEL,N)
      IF  (N.LT.6) GOTO 50
      CALL        LOOP4 (CA,HP,C,A,HR,F,ALT,ZS,TIMVAL,IJ,LABEL,N)
50    IF(INDTR.EQ.1) GOTO 52
51    CONTINUE
C
```

```
C    LOOP FOR PUNCHING CARDS
C
52     WRITE (6,900)
       WRITE (6,109)
       WRITE (6,109)
       WRITE (6,602) CA
602    FORMAT (5X,5HCASE ,I2,5X,16HOPTIMUM SOLUTION)
       WRITE (6,631)
631    FORMAT (1H0,8X,1HZ,5X,5H%TIME,8X,4HTIME,9X,5HERROR,15X,6HVALUES)
       WRITE (6,632) (LABEL(I),I=2,12)
632    FORMAT   (20X,18H(ORIGINAL)   (SUM),19X,11(A4,2X))
       DO 627  I=1,5
       STIMV(I)=0.0
       DO 625  J=2,N
       STIMV(I)=STIMV(I)+TIMVAL(I,J)
625    CONTINUE
       EPROR=TTIM(I)-STIMV(I)
       IF (ABS(ERROR).LT.1.0) GOTO630
       WRITE (6,629)
629    FORMAT (5X,38HERROR IN SUM OF TIMES GREATER THAN 1.0)
630    WRITE (6,626) ZS(I),PERC(I),TTIM(I),STIMV(I),ERROR,(TIMVAL(I,J),
      1J=2,N)
626    FORMAT (2X,F10.1,F8.2,3F10.4,5X,11F6.1)
       IF (INDTR.EQ.1) GOTO 777
627    CONTINUE
777    WRITE (6,109)
       DO 608 L=2,N
       IF (DEP(L).EQ.0.0) GOTO 608
       COST(L)=C(L)/DEP(L)
608    CONTINUE
       WRITE (6,606) CA
606    FORMAT (1X,5HCASE ,I2)
       IF (IND.EQ.1) GOTO951
```

```
      WRITE (7,606) CA
951   DO 350 I=2,N
      READ (5,601) M1,M2,M3,M4,M5,M6
601   FORMAT  (6X,2A4,4X,2A4,4X,2A4)
      DO 778 J=1,5
      WRITE (6,603) M1,M2,M3,M4,COST(I),M5,M6,TIMVAL(J,I)
603   FORMAT (4X,2A4,2X,2A4,3X,F10.3,4X,2A4,2X,1H-,F10.3)
      IF (IND.EQ.1) GOTO 350
      WRITE (7,603) M1,M2,M3,M4,COST(I),M5,M6,TIMVAL(J,I)
      IF (INDTR.EQ.1) GOTO 350
778   CONTINUE
350   CONTINUE
604   CONTINUE
      STOP
      END
      SUBROUTINE LOOP1 (CA,HP,C,A,HR,F,ALT,ZS,TIMVAL,IJ,LABEL,N)
C
C   LOOP FOR 1 HP EQ APPLYING AT A TIME
C
C
      REAL C(12),A(12),HP(12),T,TIME(12),HR,B(12),D(12),X(12),Y(12),G,
     1SUM,ALT,TIMVAL(5,12),DEP(12),COST(12),STIMV(5),ERROR,PERC(5),ZS(5)
     2,TTIM(5),LABEL(12)
      INTEGER F,CA,H
200   FORMAT  (1X,2HZ=,F10.1,3X,9HY VALUES=,12F8.1)
201   FORMAT (1X,I4,8H%(TIME)=,F6.1,2X,4HHRS=,8X,11F8.1)
202   FORMAT (13X,12HHORSE POWER=,12F8.1)
114   FORMAT (1X,22HZ VALUE TOO LARGE   Z=,F10.3)
115   FORMAT (1X,17HHORSEPOWER FOR Y(,I2,14H) IS TOO LARGE)
109   FORMAT (1H0)
      DO 20 H=2,N
      IF (C(1).EQ.0.0) GOTO 121
      WRITE (6,106) CA,HP(H),H
```

```
106     FORMAT (1H0,10X,5HCASE ,I2,10X,3HYT=,F5.1,2HY(,I2,1H))
        IF (HP(H).NE.0.0) GOTO 121
        WRITE (6,870)
870     FORMAT (10X,20HHP=0.0 TRIAL SKIPPED)
        GOTO 20
121     WRITE (6,108) LABEL
108     FORMAT ('0',29X,12(A4,4X))
        DO 1 I=1,N
1       B(I)=C(I)
        B(H)=C(1)*HP(H)+C(H)
        DO 2 I=2,N
        D(I)=B(I)*A(I)/A(H)
2       CONTINUE
        SUM=0.0
        DO 5 K=2,N
5       SUM=SUM+SQRT(D(K))
        DO 4 J=2,N
        IF(HR.EQ.0.0.OR.D(J).EQ.0.0) GOTO 4
        Y(J)=A(J)/HR*SUM/SQRT(D(J))
4       CONTINUE
        Y(1)=HP(H)*Y(H)
        DO 8 L=2,12
8       X(L)=HP(L)*Y(L)
        Z=0.0
        DO 7 M=1,N
7       Z=Z+C(M)*Y(M)
        WRITE (6,200) Z,(Y(J),J=1,N)
        DO 6 L=2,N
6       TIME (L)=A(L)/Y(L)
        WRITE (6,201) F,HR,(TIME(L),L=2,N)
        IF (C(1).EQ.0.0) GOTO 207
        WRITE (6,202) Y(1),(X(L),L=2,N)
        DO 203 J=2,N
```

```
203   IF (X(J).GT.Y(1)) GOTO41
      IF (ZS(IJ).LT.Z) GOTO 49
207   ZS(IJ)=Z
      DO 901 IK=2,N
901   TIMVAL(IJ,IK)=TIME(IK)
      GOTO 47
49    WRITE (6,114) Z
      GOTO 47
41    WRITE (6,115) J
47    IF (C(1).LT.0.001) GOTO 51
20    CONTINUE
51    RETURN
      END
      SUBROUTINE LOOPA (CA,HP,C,A,HR,F,ALT,ZS,TIMVAL,IJ,LABEL,N)
C
C    LOOP FOR ALL HP EQ APPLYING AT A TIME
C
C
      WRITE (6,109)
      REAL C(12),A(12),HP(12),T,TIME(12),HR,B(12),D(12),X(12),Y(12),G,
     1SUM,ALT,TIMVAL(5,12),DEP(12),COST(12),STIMV(5),ERROR,PERC(5),ZS(5)
     2,TTIM(5),LABEL(20)
      INTEGER F,CA
200   FORMAT  (1X,2HZ=,F10.1,3X,9HY VALUES=,12F8.1)
201   FORMAT (1X,I4,8H%(TIME)=,F6.1,2X,4HHRS=,8X,11F8.1)
202   FORMAT (13X,12HHORSE POWER=,12F8.1)
114   FORMAT (1X,22HZ VALUE TOO LARGE    Z=,F10.3)
115   FORMAT (1X,17HHORSEPOWER FOR Y(,I2,14H) IS TOO LARGE)
109   FORMAT (1H0)
108   FORMAT ('0',29X,12(A4,4X))
870   FORMAT (10X,20HHP=0.0 TRIAL SKIPPED)
      WRITE (6,107) CA
107   FORMAT (1H0,5HCASE ,I2,10X,31HALL HORSE POWER EQUATIONS APPLY)
```

```
      DO 860 K=2,N
860   IF (HP(K).EQ.0.0) GOTO 861
      WRITE (6,108) LABEL
      X(1)=0.0
      DO 69 I=2,N
69    X(1)=X(1)+A(I)*HP(I)
      DO 70 I=2,N
      IF (HP(I).EQ.0.0.OR.HR.EQ.0.0) GOTO 70
      Y(I)=X(1)/(HP(I)*HR)
70    CONTINUE
      Y(1)=X(1)/HR
      Z=0.0
      DO67 M=1,N
67    Z=Z+C(M)*Y(M)
      WRITE (6,200) Z,(Y(I),I=1,N)
      DO66 L=2,N
66    TIME (L)=A(L)/Y(L)
      WRITE (6,201) F,HR,(TIME(L),L=2,N)
      IF (ZS(IJ).LT.Z) GOTO 72
      ZS(IJ)=Z
700   DO 850 IK=2,N
850   TIMVAL(IJ,IK)=TIME(IK)
      GOTO 73
72    WRITE (6,114) Z
      GO TO 73
861   WRITE (6,862)
862   FORMAT  (10X,26HONE HP=0.0   TRIAL SKIPPED)
73    RETURN
      END
      SUBROUTINE LOOP2 (CA,HP,C,A,HR,F,ALT,ZS,TIMVAL,IJ,LABEL,N)
C
C   LOOP FOR 2 HP EQ APPLYING AT A TIME
C
```

```
C
      REAL C(12),A(12),HP(12),T,TIME(12),HR,B(12),D(12),X(12),Y(12),G,
     1SUM,ALT,TIMVAL(5,12),DEP(12),COST(12),STIMV(5),ERROR,PERC(5),ZS(5)
     2,TTIM(5),LABEL(12)
      INTEGER F,CA
200   FORMAT  (1X,2HZ=,F10.1,3X,9HY VALUES=,12F8.1)
201   FORMAT (1X,I4,8H%(TIME)=,F6.1,2X,4HHRS=,8X,11F8.1)
202   FORMAT (13X,12HHORSE POWER=,12F8.1)
114   FORMAT (1X,22HZ VALUE TOO LARGE   Z=,F10.3)
115   FORMAT (1X,17HHORSEPOWER FOR Y(,I2,14H) IS TOO LARGE)
109   FORMAT (1H0)
108   FORMAT ('0',29X,12(A4,4X))
870   FORMAT (10X,20HHP=0.0 TRIAL SKIPPED)
      WRITE (6,109)
      NM1=N-1
      DO 10 I=2,NM1
      IP1=I+1
      DO 11 J=IP1,N
      WRITE (6,300) CA ,HP(I),I,HP(J),J
300   FORMAT (1H0,10X,5HCASE ,I2,6X,3HYT=,F5.1,2HY(,I2,1H),10X,3HYT=,
     1F5.1,2HY(,I2,1H))
      IF   (HP(I).NE.0.0.AND.HP(J).NE.0.0) GOTO 210
      WRITE (6,870)
      GOTO 11
210   WRITE (6,108) LABEL
      IF (HP(I).EQ.0.0.OR.HP(J).EQ.0.0) GOTO 205
      B(1)=C(1)+C(I)/HP(I)+C(J)/HP(J)
205   DO 13 K=2,N
      IF (K.EQ.I.OR.K.EQ.J) GOTO 13
      B(K)=C(K)
13    CONTINUE
      ALT=A(I)*HP(I)+A(J)*HP(J)
      D(1)=B(1)
```

```
      DO 14 K=2,N
      IF (K.EQ.I.OR.K.EQ.J) GOTO 14
      IF (ALT.EQ.0.0) GOTO 14
      D(K)=B(K)*A(K)/ALT
14    CONTINUE
      SUM=0.0
      DO 15 K=1,N
      IF (K.EQ.I.OR.K.EQ.J) GOTO 19
      IF (D(K).EQ.0.0) GOTO 19
      SUM=SUM+SQRT(D(K))
19    CONTINUE
15    CONTINUE
      IF (HR.EQ.0.0.OR.D(1).EQ.0.0) GOTO 204
      Y(1)=ALT/HR*SUM/SQRT(D(1))
204   DO 18 L=2,N
      IF (L.EQ.I.OR.L.EQ.J) GOTO 17
      IF (HR.EQ.0.0.OR.D(L).EQ.0.0) GOTO 18
      Y(L)=A(L)/HR*SUM/SQRT(D(L))
      GO TO 18
17    IF (HP(L).EQ.0.0) GOTO 18
      Y(L)=Y(1)/HP(L)
18    CONTINUE
      Z=0.0
      DO57 M=1,N
57    Z=Z+C(M)*Y(M)
      DO58 L=2,N
58    X(L)=HP(L)*Y(L)
      WRITE (6,200) Z,(Y(L),L=1,N)
      DO56 L=2,N
      IF (Y(L).EQ.0.0) GOTO 56
      TIME (L)=A(L)/Y(L)
56    CONTINUE
      WRITE (6,201) F,HR,(TIME(L),L=2,N)
```

```
      WRITE (6,202) Y(1),(X(L),L=2,N)
      DO 74 L=2,N
74    IF (X(L).GT.Y(1)) GOTO 76
      IF (ZS(IJ).LT.Z) GOTO 75
      ZS(IJ)=Z
701   DO 851 IK=2,N
851   TIMVAL(IJ,IK)=TIME(IK)
      GOTO 11
75    WRITE (6,114) Z
      GOTO 11
76    WRITE (6,115) L
11    CONTINUE
10    CONTINUE
      RETURN
      END
      SUBROUTINE LOOP3 (CA,HP,C,A,HR,F,ALT,ZS,TIMVAL,IJ,LABEL,N)
C
C   LOOP FOR 3 HP EQ APPLYING AT A TIME
C
C
      REAL C(12),A(12),HP(12),T,TIME(12),HR,B(12),D(12),X(12),Y(12),G,
     1SUM,ALT,TIMVAL(5,12),DEP(12),COST(12),STIMV(5),ERROR,PERC(5),ZS(5)
     2,TTIM(5),LABEL(12)
      INTEGER F,CA
200   FORMAT  (1X,2HZ=,F10.1,3X,9HY VALUES=,12F8.1)
201   FORMAT (1X,I4,8H%(TIME)=,F6.1,2X,4HHRS=,8X,11F8.1)
202   FORMAT (13X,12HHORSE POWER=,12F8.1)
114   FORMAT (1X,22HZ VALUE TOO LARGE    Z=,F10.3)
115   FORMAT (1X,17HHORSEPOWER FOR Y(,I2,14H) IS TOO LARGE)
108   FORMAT ('0',29X,12(A4,4X))
870   FORMAT (10X,20HHP=0.0 TRIAL SKIPPED)
      NM1=N-1
      NM2=N-2
```

```
      DO 30 I1=2,NM2
      I1P1=I1+1
      DO 31 I2=I1P1,NM1
      I2P1=I2+1
      DO 32 I3=I2P1,N
      WRITE (6,400) CA,HP(I1),I1,HP(I2),I2,HP(I3),I3
400   FORMAT (1H0,5HCASE ,I2,6X,3HYT=,F5.1,2HY(,I2,1H),10X,3HYT=,F5.1,
     12HY(,I2,1H),10X,3HYT=,F5.1,2HY(,I2,1H))
      IF  (HP(I1).NE.0.0.AND.HP(I2).NE.0.0.AND.HP(I3).NE.0.0) GOTO 211
      WRITE (6,870)
      GOTO 32
211   WRITE (6,108) LABEL
      IF (HP(I1).EQ.0.0.OR.HP(I2).EQ.0.0.OR.HP(I3).EQ.0.0) GOTO 401
      B(1)=C(1)+C(I1)/HP(I1)+C(I2)/HP(I2)+C(I3)/HP(I3)
401   DO 33 K=2,N
      IF (K.EQ.I1.OR.K.EQ.I2.OR.K.EQ.I3) GOTO 33
      B(K)=C(K)
33    CONTINUE
      ALT=A(I1)*HP(I1)+A(I2)*HP(I2)+A(I3)*HP(I3)
      D(1)=B(1)
      DO 34 K=2,N
      IF (K.EQ.I1.OR.K.EQ.I2.OR.K.EQ.I3) GOTO 34
      IF (ALT.EQ.0.0 ) GOTO 34
      D(K)=B(K)*A(K)/ALT
34    CONTINUE
      SUM=0.0
      DO 35 K=1,N
      IF (K.EQ.I1.OR.K.EQ.I2.OR.K.EQ.I3) GOTO 35
      IF (D(K).EQ.0.0) GOTO 35
      SUM =SUM+SQRT(D(K))
35    CONTINUE
      IF (HR.EQ.0.0.OR.D(1).EQ.0.0) GOTO 402
      Y(1)=ALT/HR*SUM/SQRT(D(1))
```

```
402   DO 38 L=2,N
      IF (L.EQ.I1.OR.L.EQ.I2.OR.L.EQ.I3) GOTO 37
      IF (HR.EQ.0.0.OR.D(L).EQ.0.0) GOTO 38
      Y(L)=A(L)/HR*SUM/SQRT(D(L))
      GOTO 38
37    IF (HP(L).EQ.0.0) GOTO 38
      Y(L)=Y(1)/HP(L)
38    CONTINUE
      Z=0.0
      DO 88 M=1,N
88    Z=Z+C(M)*Y(M)
      DO 89 L=2,N
89    X(L)=HP(L)*Y(L)
      WRITE (6,200) Z,(Y(L),L=1,N)
      DO81 L=2,N
      IF (Y(L).EQ.0.0) GOTO 81
      TIME (L)=A(L)/Y(L)
81    CONTINUE
      WRITE (6,201) F,HR,(TIME(L),L=2,N)
      WRITE (6,202) Y(1),(X(L),L=2,N)
      DO 206 J=2,N
206   IF (X(J).GT.Y(1)) GOTO 42
      IF (ZS(IJ).LT.Z) GOTO 43
      ZS(IJ)=Z
702   DO 852 IK=2,N
852   TIMVAL(IJ,IK)=TIME(IK)
36    CONTINUE
      GOTO 32
43    WRITE (6,114) Z
      GOTO 32
42    WRITE (6,115) J
32    CONTINUE
31    CONTINUE
```

```
30    CONTINUE
      RETURN
      END
      SUBROUTINE LOOP4 (CA,HP,C,A,HR,F,ALT,ZS,TIMVAL,IJ,LABEL,N)
C
C   LOOP FOR 4 HP EQUATIONS APPLYING AT A TIME
C
C
      REAL C(12),A(12),HP(12),T,TIME(12),HR,B(12),D(12),X(12),Y(12),G,
     1SUM,ALT,TIMVAL(5,12),DEP(12),COST(12),STIMV(5),ERROR,PERC(5),ZS(5)
     2,TTIM(5),LABEL(12)
      INTEGER F,CA
200   FORMAT  (1X,2HZ=,F10.1,3X,9HY VALUES=,12F8.1)
201   FORMAT (1X,I4,8H%(TIME)=,F6.1,2X,4HHRS=,8X,11F8.1)
202   FORMAT (13X,12HHORSE POWER=,12F8.1)
114   FORMAT (1X,22HZ VALUE TOO LARGE   Z=,F10.3)
115   FORMAT (1X,17HHORSEPOWER FOR Y(,I2,14H) IS TOO LARGE)
108   FORMAT ('0',29X,12(A4,4X))
109   FORMAT (1H0)
870   FORMAT (10X,20HHP=0.0 TRIAL SKIPPED)
      NM1=N-1
      NM2=N-2
      NM3=N-3
      DO 450 I1=2,NM3
      I1P1=I1+1
      DO 451 I2=I1P1,NM2
      I2P1=I2+1
      DO 452 I3=I2P1,NM1
      I3P1=I3+1
      DO 453 I4=I3P1,N
      WRITE (6,454) CA,HP(I1),I1,HP(I2),I2,HP(I3),I3,HP(I4),I4
454   FORMAT   (1H0,10X,5HCASE ,I2,6X,3HYT=,F5.1,2HY(,I2,1H),10X,3HYT=,
     1F5.1,2HY(,I2,1H),10X,3HYT=,F5.1,2HY(,I2,1H),10X,3HYT=,F5.1,2HY(,
```

```
     2 I2,1H))
      IF (HP(I1).NE.0.0.AND.HP(I2).NE.0.0.AND.HP(I3).NE.0.0.AND.HP(I4).
     1NE.0.0) GOTO 455
      WRITE (6,870)
      GOTO 453
455   WRITE (6,108) LABEL
      IF (HP(I1).EQ.0.0.OR.HP(I2).EQ.0.0.OR.HP(I3).EQ.0.0.OR.HP(I4).EQ.0
     1.0) GOTO 470
      B(1)=C(1)+C(I1)/HP(I1)+C(I2)/HP(I2)+C(I3)/HP(I3)+C(I4)/HP(I4)
470   DO 456 K=2,N
      IF  (K.EQ.I1.OR.K.EQ.I2.OR.K.EQ.I3.OR.K.EQ.I4) GOTO 456
      B(K)=C(K)
456   CONTINUE
      ALT =A(I1)*HP(I1)+A(I2)*HP(I2)+A(I3)*HP(I3)+A(I4)*HP(I4)
      D(1)=B(1)
      DO 457 K=2,N
      IF  (K.EQ.I1.OR.K.EQ.I2.OR.K.EQ.I3.OR.K.EQ.I4) GOTO 457
      IF (ALT.EQ.0.0) GOTO 457
      D(K)=B(K)*A(K)/ALT
457   CONTINUE
      SUM =0.0
      DO 458 K=1,N
      IF  (K.EQ.I1.OR.K.EQ.I2.OR.K.EQ.I3.OR.K.EQ.I4) GOTO 458
      IF (D(K).EQ.0.0) GOTO 458
      SUM=SUM+SQRT(D(K))
458   CONTINUE
      IF (HR.EQ.0.0.OR.D(1).EQ.0.0) GOTO459
      Y(1)=ALT/HR*SUM/SQRT(D(1))
459   DO 460 K=2,N
      IF  (K.EQ.I1.OR.K.EQ.I2.OR.K.EQ.I3.OR.K.EQ.I4) GOTO 461
      IF (HR.EQ.0.0.OR.D(K).EQ.0.0) GOTO460
      Y(K)=A(K)/HR*SUM/SQRT(D(K))
      GOTO 460
```

```
461   IF  (HP(K).EQ.0.0) GOTO 460
      Y(K)=Y(1)/HP(K)
460   CONTINUE
      Z=0.0
      DO 462 M=1,N
462   Z=Z+C(M)*Y(M)
      DO 463 L=2,N
463   X(L)=HP(L)*Y(L)
      WRITE (6,200) Z,(Y(L),L=1,N)
      DO 464 L=2,N
      IF (Y(L).EQ.0.0) GOTO 464
      TIME(L)=A(L)/Y(L)
464   CONTINUE
      WRITE (6,201) F,HR,(TIME(L),L=2,N)
      WRITE (6,202) Y(1),(X(L),L=2,N)
      DO 465 J=2,N
465   IF (X(J).GT.Y(1)) GOTO 466
      IF (ZS(IJ).LT.Z) GOTO 467
      ZS(IJ)=Z
      DO  468 IK=2,N
468   TIMVAL (IJ,IK)=TIME(IK)
      GOTO 453
467   WRITE (6,114) Z
      GOTO 453
466   WRITE (6,115) J
453   CONTINUE
452   CONTINUE
451   CONTINUE
450   CONTINUE
      RETURN
      END
```

EXAMPLE INPUT DATA FOR LAGRANCE MULTIPLIER PROGRAM

```
   2
  YT   YC   YD   YH
   1      4    480.
          8.9  5.6   1.4
         7.    7.    7.
  117.  182.  500.   44.4
          703. 1881.  1881.
C59        R0                         R31
C60        R0                         R29
C61        R0                         R30
       YS   YC
   1      3    450.
          0.0   0.0
         7.    7.
          655.  2690.
         1781.  1781.
C62        R0                         R32
C63        R0                         R33
```

APPENDIX E

EXAMPLE LINEAR AND SEPARABLE PROGRAMMING COMPUTER CONTROL PROGRAMS AND DATA

The computer card listings contained in this appendix are examples of those used in the mathematical programming computer runs and are used with the IBM 360 Linear and Separable Programming Package (15). The first one (on the next page) is the control program for case 1 for determining the optimum combination of field machines. On page three is a listing of the input data (with the bulk of cards omitted) for case 1 for determining the optimum combination of field machines. On page four is a listing of the control program used for case 1 when the linear program was solved successively for the different field machine time allotments. For this run the linear program data deck was like the listing on page three except that there was no "bounds" section, and there was a revise data deck for each of the time changes.

```
PROGRAM
 INITIALZ
TITLE ('CASE 1    -    RUN 1')
 MOVE(XDATA,'CASE101')
 MOVE(XPBNAME,'CASE1R1')
 MOVE(XOBJ,'RO')
MOVE(XRHS,'H')
 CONVERT('SUMMARY')
BCDOUT
SETUP('BOUND','BD')
 PRIMAL
 SOLUTION
 RANGE
 EXIT
 PEND
```

```
NAME          CASE101
ROWS
 N  R0
 L  R1
 L  R2
 E  R3
 L  R4
         .
         .
         .
 L  R31
 L  RCB
 L  S1
COLUMNS
    C1        R0         -26.65
    C1        R4         1.              R5        0.
    C1        R8         -.2             R24       -.5
    C1        R29        1.
    C1        R30        1.              R31       1.
    C1        RCB        1.              S1        1.
    C2        R0         -36.15          R1        1.
    C2        R2         1.              R4        1.
         .
         .
         .
    TT        R27        -1.             R28       -1.
    C59       R0              26.000     R31       -    138.472
    C59       R26        8.9
    C60       R0              73.571     R29       -     87.128
    C60       R27        4.3
    C61       R0               6.286     R30       -     24.400
    C61       R28        1.4
    CBM       R0         4.6             RCB       -1.
    Z1        'MARKER'                   'SEPORG'
    SC1       S1         -50.
    SC1       R0         500.
    SC2       S1         -50.
    SC2       R0         1.
    Z2        'MARKER'                   'SEPEND'
RHS
    H         R1         1585.           R2        100.
    H         R3         370.            R7        6000.
         .
         .
         .
    H         R25        150.
BOUNDS
 UP BD        SC1        1.
ENDATA
```

```
PROGRAM
INITIALZ
 MOVE(XDATA,'CASE101')
 MOVE(XPBNAME,'CASE1R1')
 MOVE(XOBJ,'RO')
MOVE(XRHS,'H')
 CONVERT('SUMMARY')
BCDOUT
SETUP
 PRIMAL
 SOLUTION
 MOVE(XDATA,'CASE102')
 MOVE(XPBNAME,'CASE1R2')
 MOVE(XOLDNAME,'CASE1R1')
 REVISE('SUMMARY')
BCDOUT
SETUP
 PRIMAL
 SOLUTION
 MOVE(XDATA,'CASE103')
 MOVE(XPBNAME,'CASE1R3')
 MOVE(XOLDNAME,'CASE1R2')
 REVISE('SUMMARY')
BCDOUT
SETUP
 PRIMAL
 SOLUTION
 MOVE(XDATA,'CASE104')
 MOVE(XPBNAME,'CASE1R4')
 MOVE(XOLDNAME,'CASE1R3')
 REVISE('SUMMARY')
BCDOUT
SETUP
 PRIMAL
 SOLUTION
 MOVE(XDATA,'CASE105')
 MOVE(XPBNAME,'CASE1R5')
 MOVE(XOLDNAME,'CASE1R4')
 REVISE('SUMMARY')
BCDOUT
SETUP
 PRIMAL
 SOLUTION
EXIT
PEND
```

APPENDIX F

SIMULATION COMPUTER PROGRAM FOR CALCULATING HARVEST PENALTY COSTS

The listing contained in this section is for the harvest simulation program for determining the penalties associated with adverse weather during grain harvesting. The program was written by Coates (3) and revised by the author. The IBM General Purpose Simulation System (8) was used rather than using a source language. All data is included in the program in the form of functions.

```
          SIMULATE
         1 FUNCTION    X2,D19
10       2       20    2      30     2      40     2      50     2      60     2
70       3       80    3      90     3      100    3      110    3      120    3
130      3       140   3      150    4      160    4      170    4      180    4
190      5
         2 FUNCTION    X2,D19
10       2       20    2      30     2      40     3      50     3      60     4
70       4       80    4      90     5      100    5      110    6      120    6
130      6       140   6      150    7      160    7      170    7      180    7
190      7
         3 FUNCTION    X2,D19
10       2       20    3      30     3      40     4      50     5      60     5
70       6       80    6      90     7      100    7      110    7      120    7
130      7       140   7      150    7      160    7      170    7      180    7
190      7
         4 FUNCTION    X2,D19
10       2       20    3      30     4      40     5      50     6      60     7
70       7       80    7      90     7      100    7      110    7      120    7
130      7       140   7      150    7      160    7      170    7      180    7
190      7
         5 FUNCTION    X2,D19
10       2       20    4      30     4      40     5      50     6      60     7
70       7       80    7      90     7      100    7      110    7      120    7
130      7       140   7      150    7      160    7      170    7      180    7
190      7
         6 FUNCTION    X2,D19
10       3       20    4      30     5      40     7      50     7      60     7
70       7       80    7      90     7      100    7      110    7      120    7
130      7       140   7      150    7      160    7      170    7      180    7
190      7
         7 FUNCTION    X2,D19
10       3       20    4      30     5      40     7      50     7      60     7
```

```
70      7       80      7       90      7       100     7       110     7       120     7
130     7       140     7       150     7       160     7       170     7       180     7
190     7
      8 FUNCTION    X24,L7
       00           9,0           30            48            66            72
       78
      9 FUNCTION    X4,L7
       00           9,0           30            48            66            72
       78
     10 FUNCTION    RN3,D18
,1451 5,0   ,2742 10,   ,2903 15,   ,4355 20,   ,5806 30,   ,6612 40,
,7258 50,   ,7581 55,   ,7903 60,   ,8065 65,   ,8387 70,   ,8871 90,
,9194 100,  ,9355 110,  ,9516 120,  ,9677 130,  ,9839 160,  1,000 180,
     11 FUNCTION    RN4,D23
,0921 5,0   ,1974 10,   ,2234 15,   ,3553 20,   ,3816 25,   ,5000 30,
,5526 40,   ,6316 50,   ,6447 55,   ,6974 60,   ,7105 65,   ,7763 70,
,7895 75,   ,8158 80,   ,8421 90,   ,8684 100,  ,8947 110,  ,9342 120,
,9474 130,  ,9605 210,  ,9737 240,  ,9868 250,  1,000 390,
        GENERATE    3650,,,1000
        SAVEVALUE   1,0                          INITIALIZE SAVEVALUES
        SAVEVALUE   2,0
        SAVEVALUE   3,0
        SAVEVALUE   4,0
        SAVEVALUE   7,0
        SAVEVALUE   8,0
        SAVEVALUE   9,0
        SAVEVALUE   10,0
        SAVEVALUE   11,0
        SAVEVALUE   12,0
        SAVEVALUE   13,0
        SAVEVALUE   14,0
        SAVEVALUE   15,0
        SAVEVALUE   16,0
```

```
      SAVEVALUE  17,0
      SAVEVALUE  18,0
      SAVEVALUE  19,0
      SAVEVALUE  20,0
      SAVEVALUE  21,0
      SAVEVALUE  22,0
      SAVEVALUE  23,0
      SAVEVALUE  24,K2
      SAVEVALUE  25,0
      SAVEVALUE  26,K10000
    1 VARIABLE   RN1@100                      TEST FOR GOOD OR BAD START
      TEST G     V1,65,GOOD
  BAD LOGIC R    1
      TRANSFER   ,GOOT
 GOOD LOGIC S    1
 ROOT SAVEVALUE  1,FN11                       GOOD DAYS
 GOOT SAVEVALUE  2,FN10                       BAD DAYS
      ASSIGN     1,X2
      SAVEVALUE  6,K1
      SAVEVALUE  5,0
    2 VARIABLE   X3+X1
      SAVEVALUE  3,V2
      SAVEVALUE  25+,K1
      ASSIGN     2,X25
      TEST G     X25,7,SAVE
      ASSIGN     2,K7
 SAVE SAVEVALUE  4,FN*2
      TEST L     X24,X4,NOPEN
    3 VARIABLE   FN9-FN8
      SAVEVALUE  5,V3                         PENALTY PER ACRE TIMES TEN
NOPEN SAVEVALUE  24,X4
      SPLIT      1,BIG
```

```
         SAVEVALUE  6+,K1
         SPLIT      1,SECON
         SAVEVALUE  6+,K1
         SPLIT      1,THIRD
         SAVEVALUE  6+,K1
         SPLIT      1,FORTH
         SAVEVALUE  6+,K1
         GATE LS    1,BADES                   SMALLEST COMBINE ROUTINE
         ADVANCE    X1
       4 VARIABLE   X1*K20+X7                 ACRES DONE TIMES TEN
         SAVEVALUE  7,V4
   BADES ADVANCE    X2
       5 VARIABLE   X26-X7                    ACRES LEFT TIMES TEN
         SAVEVALUE  8,V5
         TEST G     X8,0,ONE
       6 VARIABLE   (X5*X8)/K100+X9
         SAVEVALUE  9,V6
     ONE TEST LE    X8,0,TWEO
         SAVEVALUE  8,0
    TWEO TEST G     X6,1,LOGI
         TRANSFER   ,ASSEM
     BIG GATE LS    1,BADER                   BIGGEST COMBINE ROUTINE
         ADVANCE    X1
       7 VARIABLE   X1*K170+X10               ACRES DONE TIMES TEN
         SAVEVALUE  10,V7
   BADER ADVANCE    X2
       8 VARIABLE   X26-X10                   ACRES LEFT TIMES TEN
         SAVEVALUE  11,V8
         TEST G     X11,0,THREE
       9 VARIABLE   (X5*X11)/K100+X12
```

```
      SAVEVALUE  12,V9
THREE TEST LE    X11,0,ASSEM
      SAVEVALUE  11,0
      TRANSFER   ,ASSEM
SECON GATE LS    1,BADET               BIG COMBINE ROUTINE
      ADVANCE    X1
   10 VARIABLE   X1*K110+X13           ACRES DONE TIMES TEN
      SAVEVALUE  13,V10
BADET ADVANCE    X2
   11 VARIABLE   X26-X13               ACRES LEFT TIMES TEN
      SAVEVALUE  14,V11
      TEST G     X14,0,FOUR
   12 VARIABLE   (X5*X14)/K100+X15
      SAVEVALUE  15,V12
 FOUR TEST LE    X14,0,ASSEM
      SAVEVALUE  14,0
      TRANSFER   ,ASSEM
THIRD GATE LS    1,BADEL               MEDIUM COMBINE ROUTINE
      ADVANCE    X1
   13 VARIABLE   X1*K65+X16            ACRES DONE TIMES TEN
      SAVEVALUE  16,V13
BADEL ADVANCE    X2
   14 VARIABLE   X26-X16               ACRES LEFT TIMES TEN
      SAVEVALUE  17,V14
      TEST G     X17,0,FIVE
   15 VARIABLE   (X5*X17)/K100+X18
      SAVEVALUE  18,V15
 FIVE TEST LE    X17,0,ASSEM
      SAVEVALUE  17,0
      TRANSFER   ,ASSEM
FORTH GATE LS    1,BADEE               SMALL COMBINE ROUTINE
      ADVANCE    X1
   16 VARIABLE   X1*K35+X19            ACRES DONE TIMES TEN
```

```
       SAVEVALUE   19,V16
PADFF  ADVANCE     X2
    17 VARIABLE    X25-X19                [illegible] LEFT TIMES TEN
       SAVEVALUE   20,V17
       TEST G      X20,0,SIX
    18 VARIABLE    (X5*X20)/K100+X21
       SAVEVALUE   21,V18
   SIX TEST LE     X20,0,ASSEN
       SAVEVALUE   20,0
 ASSEN ASSEMBLE    X6
  LOGI LOGIC S     1
    19 VARIABLE    X1+X2+X22              TOTAL DAYS TIMES TEN
       SAVEVALUE   22,V19
    20 VARIABLE    X8+X11+X14+X17+X20     TOTAL ACRES LEFT TIMES TEN
       SAVEVALUE   23,V20
       TEST G      X23,0,TERM
       TEST G      X22,600,ROOT
  TERM TABULATE    1
       TABULATE    2
       TABULATE    3
       TABULATE    4
       TABULATE    5
       TERMINATE   1
     1 TABLE       X9,-4000,100,600
     2 TABLE       X12,-4000,100,600
     3 TABLE       X15,-4000,100,600
     4 TABLE       X18,-4000,100,600
     5 TABLE       X21,-4000,100,600
       START       1000
       END
```

APPENDIX G

WORK DAY PROBABILITIES FOR ALBERTA

The probabilities for work days given by Rutledge (19) are based on monthly averages. However, cropping operation time periods rarely begin and end with the months of the year, and the probabilities on a daily basis are not uniform from one end of the month to the other. For these reasons, Rutledge (19) and the author wrote a computer program to calculate the probability of work days on a daily basis for the stations and soils used by Rutledge (19).

The method used was to total the x's (work days) listed by Rutledge (19) in appendix 8.1 of his thesis for each day at each station over the years available. This total was then divided by the number of possible days to arrive at the probability. The data given by Rutledge (19) was also available on magnetic tape at the Department of Agricultural Engineering, University of Alberta. This tape was used with the computer program.

The work day probabilities on a daily basis are shown in the following tables.

TABLE G 1: EDMONTON (STATION NUMBERS 2195-2208)-

PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.0	0.60	0.69	0.64	0.73	0.67	0.53
2	0.04	0.62	0.71	0.67	0.69	0.78	0.47
3	0.07	0.60	0.76	0.62	0.60	0.82	0.42
4	0.07	0.53	0.71	0.62	0.64	0.71	0.42
5	0.04	0.62	0.69	0.64	0.62	0.80	0.38
6	0.04	0.64	0.73	0.67	0.64	0.67	0.49
7	0.07	0.60	0.73	0.64	0.64	0.64	0.44
8	0.07	0.60	0.67	0.64	0.73	0.78	0.44
9	0.16	0.71	0.82	0.71	0.69	0.80	0.49
10	0.20	0.69	0.87	0.71	0.64	0.69	0.44
11	0.24	0.80	0.89	0.69	0.62	0.67	0.47
12	0.31	0.82	0.71	0.80	0.67	0.60	0.51
13	0.33	0.91	0.67	0.76	0.73	0.60	0.49
14	0.33	0.89	0.73	0.73	0.62	0.56	0.40
15	0.38	0.89	0.73	0.76	0.64	0.56	0.36
16	0.40	0.78	0.67	0.64	0.76	0.58	0.44
17	0.40	0.71	0.67	0.56	0.69	0.42	0.44
18	0.40	0.84	0.64	0.69	0.69	0.42	0.42
19	0.47	0.82	0.76	0.71	0.78	0.49	0.47
20	0.40	0.82	0.76	0.76	0.73	0.47	0.44
21	0.49	0.82	0.87	0.82	0.80	0.42	0.40
22	0.53	0.64	0.69	0.82	0.73	0.51	0.40
23	0.47	0.71	0.64	0.67	0.71	0.49	0.40
24	0.53	0.80	0.58	0.69	0.73	0.49	0.38
25	0.56	0.73	0.49	0.78	0.67	0.47	0.33
26	0.58	0.78	0.60	0.76	0.69	0.42	0.38
27	0.69	0.69	0.71	0.71	0.64	0.44	0.33
28	0.71	0.78	0.76	0.67	0.60	0.49	0.29
29	0.76	0.82	0.67	0.64	0.64	0.47	0.29
30	0.64	0.76	0.62	0.60	0.64	0.51	0.33
31	0.0	0.82	0.0	0.67	0.67	0.0	0.27

TABLE G 2: VERMILION (STATION NUMBER 6800)-

PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.0	0.60	0.80	0.65	0.75	0.55	0.45
2	0.0	0.60	0.80	0.75	0.75	0.65	0.40
3	0.0	0.55	0.85	0.80	0.75	0.60	0.45
4	0.0	0.55	0.80	0.85	0.70	0.80	0.35
5	0.0	0.70	0.70	0.75	0.80	0.80	0.35
6	0.0	0.70	0.80	0.75	0.80	0.85	0.40
7	0.05	0.65	0.80	0.75	0.85	0.75	0.40
8	0.05	0.80	0.85	0.95	0.75	0.70	0.40
9	0.10	0.90	0.80	0.90	0.80	0.70	0.45
10	0.10	0.90	0.70	0.85	0.50	0.70	0.45
11	0.15	0.95	0.75	0.75	0.60	0.60	0.45
12	0.20	0.85	0.70	0.80	0.65	0.50	0.35
13	0.25	0.80	0.65	0.85	0.65	0.60	0.40
14	0.25	0.70	0.75	0.50	0.90	0.60	0.35
15	0.30	0.80	0.55	0.60	0.85	0.50	0.40
16	0.35	0.75	0.75	0.75	0.70	0.40	0.40
17	0.40	0.80	0.60	0.60	0.65	0.45	0.50
18	0.50	0.90	0.80	0.80	0.60	0.55	0.50
19	0.40	0.95	0.80	0.75	0.75	0.50	0.50
20	0.25	0.80	0.75	0.80	0.80	0.40	0.45
21	0.30	0.80	0.75	0.75	0.90	0.40	0.40
22	0.40	0.80	0.60	0.80	0.70	0.40	0.40
23	0.50	0.90	0.65	0.80	0.85	0.40	0.40
24	0.40	0.75	0.70	0.85	0.65	0.45	0.35
25	0.55	0.80	0.65	0.55	0.60	0.45	0.35
26	0.50	0.75	0.60	0.75	0.50	0.40	0.40
27	0.55	0.85	0.80	0.60	0.55	0.40	0.40
28	0.60	0.90	0.85	0.80	0.50	0.45	0.45
29	0.60	0.90	0.60	0.80	0.65	0.35	0.40
30	0.60	0.80	0.60	0.75	0.70	0.40	0.40
31	0.0	0.80	0.0	0.85	0.65	0.0	0.35

TABLE G 3: CALGARY (STATION NUMBERS 1080-1100)-

PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.02	0.57	0.72	0.63	0.72	0.76	0.54
2	0.0	0.59	0.67	0.74	0.85	0.80	0.57
3	0.02	0.63	0.67	0.70	0.80	0.89	0.50
4	0.07	0.63	0.70	0.74	0.85	0.83	0.48
5	0.07	0.61	0.65	0.70	0.74	0.76	0.43
6	0.13	0.65	0.61	0.70	0.74	0.85	0.46
7	0.24	0.59	0.67	0.74	0.85	0.78	0.48
8	0.20	0.63	0.72	0.74	0.83	0.70	0.52
9	0.20	0.76	0.67	0.85	0.85	0.63	0.46
10	0.24	0.76	0.61	0.89	0.85	0.67	0.52
11	0.33	0.70	0.61	0.87	0.78	0.67	0.48
12	0.30	0.78	0.65	0.85	0.74	0.59	0.48
13	0.41	0.63	0.65	0.83	0.76	0.61	0.50
14	0.43	0.61	0.65	0.85	0.83	0.61	0.48
15	0.46	0.74	0.59	0.83	0.78	0.63	0.52
16	0.48	0.74	0.65	0.76	0.85	0.61	0.50
17	0.50	0.78	0.67	0.83	0.83	0.59	0.48
18	0.48	0.78	0.70	0.80	0.78	0.52	0.46
19	0.59	0.78	0.72	0.78	0.78	0.57	0.48
20	0.52	0.72	0.63	0.83	0.61	0.50	0.50
21	0.50	0.74	0.67	0.89	0.78	0.52	0.54
22	0.37	0.72	0.63	0.85	0.80	0.57	0.57
23	0.50	0.78	0.70	0.87	0.76	0.54	0.54
24	0.52	0.70	0.59	0.76	0.72	0.52	0.57
25	0.48	0.72	0.65	0.83	0.70	0.57	0.52
26	0.57	0.80	0.59	0.87	0.67	0.52	0.50
27	0.54	0.85	0.63	0.89	0.74	0.57	0.39
28	0.57	0.83	0.59	0.72	0.78	0.59	0.39
29	0.63	0.74	0.61	0.83	0.74	0.57	0.43
30	0.54	0.70	0.74	0.78	0.78	0.59	0.43
31	0.0	0.74	0.0	0.80	0.85	0.0	0.41

TABLE G 4: LETHBRIDGE (STATION NUMBERS [illegible])-

PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.02	0.67	0.73	0.80	0.91	0.80	0.58
2	0.02	0.67	0.69	0.84	0.96	0.76	0.60
3	0.02	0.73	0.71	0.82	0.91	0.80	0.60
4	0.11	0.64	0.71	0.84	0.91	0.87	0.60
5	0.22	0.76	0.73	0.84	0.91	0.71	0.56
6	0.29	0.78	0.69	0.93	0.89	0.82	0.60
7	0.27	0.71	0.73	0.78	0.89	0.73	0.60
8	0.29	0.76	0.69	0.82	0.89	0.73	0.53
9	0.33	0.76	0.64	0.84	0.87	0.76	0.64
10	0.44	0.76	0.67	0.82	0.82	0.67	0.64
11	0.49	0.67	0.69	0.82	0.89	0.64	0.62
12	0.60	0.73	0.64	0.89	0.87	0.69	0.53
13	0.60	0.64	0.69	0.96	0.91	0.73	0.56
14	0.51	0.71	0.69	0.80	0.93	0.76	0.56
15	0.60	0.73	0.76	0.91	0.82	0.71	0.62
16	0.60	0.76	0.73	0.80	0.87	0.71	0.69
17	0.62	0.80	0.76	0.89	0.91	0.69	0.67
18	0.56	0.73	0.73	0.98	0.91	0.60	0.64
19	0.67	0.76	0.78	0.87	0.87	0.64	0.58
20	0.56	0.80	0.71	0.84	0.87	0.60	0.56
21	0.58	0.73	0.67	0.96	0.84	0.62	0.56
22	0.49	0.73	0.69	0.91	0.82	0.60	0.53
23	0.53	0.76	0.76	0.91	0.84	0.58	0.51
24	0.58	0.71	0.76	0.87	0.78	0.62	0.58
25	0.53	0.76	0.78	0.87	0.78	0.62	0.58
26	0.60	0.80	0.71	0.91	0.82	0.56	0.51
27	0.51	0.78	0.76	0.87	0.82	0.56	0.49
28	0.60	0.78	0.73	0.82	0.80	0.58	0.49
29	0.67	0.76	0.80	0.89	0.82	0.58	0.49
30	0.60	0.80	0.84	0.91	0.76	0.58	0.53
31	0.0	0.78	0.0	0.91	0.87	0.0	0.49

TABLE G 5: MEDICINE HAT (STATION NUMBER 4480)-

PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.04	0.76	0.71	0.78	0.91	0.89	0.67
2	0.07	0.73	0.91	0.87	0.96	0.84	0.71
3	0.09	0.76	0.71	0.89	0.93	0.82	0.69
4	0.11	0.71	0.76	0.87	0.93	0.78	0.71
5	0.16	0.76	0.78	0.87	0.91	0.82	0.73
6	0.24	0.78	0.78	0.84	0.91	0.89	0.71
7	0.24	0.78	0.82	0.87	0.87	0.84	0.71
8	0.31	0.84	0.82	0.89	0.84	0.71	0.62
9	0.33	0.84	0.69	0.91	0.82	0.84	0.64
10	0.33	0.73	0.76	0.91	0.84	0.69	0.64
11	0.53	0.84	0.84	0.89	0.84	0.67	0.67
12	0.58	0.84	0.76	0.91	0.91	0.71	0.60
13	0.62	0.84	0.76	0.87	0.91	0.71	0.62
14	0.51	0.78	0.71	0.89	0.89	0.76	0.64
15	0.67	0.84	0.69	0.89	0.80	0.69	0.64
16	0.62	0.87	0.76	0.84	0.87	0.71	0.67
17	0.67	0.84	0.82	0.87	0.91	0.76	0.69
18	0.78	0.84	0.80	0.87	0.93	0.73	0.71
19	0.80	0.84	0.82	0.89	0.89	0.67	0.67
20	0.69	0.80	0.84	0.78	0.84	0.64	0.67
21	0.73	0.80	0.80	0.89	0.82	0.58	0.56
22	0.67	0.78	0.78	0.98	0.87	0.60	0.53
23	0.64	0.80	0.73	0.93	0.89	0.60	0.56
24	0.73	0.82	0.82	0.93	0.67	0.62	0.62
25	0.67	0.80	0.80	0.82	0.78	0.60	0.60
26	0.62	0.87	0.67	0.91	0.80	0.64	0.67
27	0.71	0.84	0.78	0.91	0.84	0.60	0.64
28	0.76	0.80	0.71	0.89	0.82	0.62	0.60
29	0.73	0.82	0.80	0.89	0.82	0.58	0.56
30	0.69	0.78	0.76	0.98	0.80	0.62	0.49
31	0.0	0.78	0.0	0.89	0.87	0.0	0.44

TABLE G 6: BEAVERLODGE (STATION NUMBER 560)-

PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.0	0.53	0.89	0.84	0.80	0.60	0.24
2	0.0	0.56	0.91	0.80	0.76	0.67	0.24
3	0.0	0.60	0.82	0.84	0.76	0.58	0.18
4	0.02	0.71	0.82	0.80	0.67	0.56	0.22
5	0.02	0.73	0.80	0.73	0.73	0.62	0.24
6	0.0	0.71	0.87	0.78	0.71	0.64	0.24
7	0.02	0.71	0.78	0.71	0.78	0.62	0.27
8	0.02	0.71	0.89	0.71	0.82	0.64	0.29
9	0.04	0.73	0.78	0.76	0.80	0.67	0.27
10	0.04	0.78	0.78	0.73	0.76	0.62	0.22
11	0.07	0.84	0.78	0.80	0.76	0.58	0.18
12	0.07	0.76	0.69	0.80	0.73	0.53	0.11
13	0.07	0.71	0.76	0.78	0.69	0.51	0.16
14	0.09	0.73	0.78	0.71	0.64	0.51	0.18
15	0.09	0.82	0.78	0.73	0.60	0.51	0.13
16	0.09	0.82	0.76	0.71	0.69	0.42	0.16
17	0.13	0.89	0.76	0.69	0.73	0.38	0.16
18	0.11	0.82	0.73	0.69	0.80	0.40	0.13
19	0.11	0.76	0.64	0.82	0.80	0.36	0.09
20	0.13	0.80	0.76	0.76	0.67	0.36	0.07
21	0.16	0.82	0.76	0.91	0.71	0.31	0.04
22	0.16	0.80	0.71	0.84	0.71	0.36	0.07
23	0.20	0.78	0.73	0.78	0.64	0.40	0.07
24	0.24	0.78	0.87	0.87	0.73	0.33	0.07
25	0.31	0.73	0.71	0.69	0.67	0.31	0.07
26	0.42	0.73	0.64	0.64	0.64	0.27	0.04
27	0.49	0.78	0.71	0.69	0.71	0.29	0.04
28	0.49	0.73	0.78	0.64	0.73	0.27	0.04
29	0.56	0.71	0.78	0.76	0.67	0.27	0.04
30	0.58	0.82	0.78	0.76	0.60	0.29	0.04
31	0.0	0.82	0.0	0.73	0.58	0.0	0.04

TABLE G 7: FAIRVIEW (STATION NUMBER 2520)-

PROBABILITY OF A WORK DAY ON MEDIUM TO HEAVY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.03	0.56	0.79	0.76	0.68	0.50	0.38
2	0.0	0.56	0.88	0.74	0.79	0.50	0.32
3	0.0	0.65	0.88	0.71	0.74	0.74	0.29
4	0.03	0.74	0.85	0.68	0.76	0.50	0.38
5	0.0	0.71	0.94	0.62	0.74	0.56	0.38
6	0.0	0.76	0.82	0.82	0.68	0.65	0.29
7	0.0	0.74	0.82	0.79	0.74	0.65	0.26
8	0.03	0.74	0.82	0.71	0.82	0.59	0.24
9	0.03	0.79	0.79	0.71	0.88	0.68	0.29
10	0.06	0.76	0.85	0.74	0.76	0.59	0.24
11	0.09	0.76	0.88	0.85	0.68	0.56	0.24
12	0.09	0.82	0.71	0.82	0.68	0.59	0.12
13	0.09	0.76	0.65	0.79	0.65	0.65	0.12
14	0.06	0.85	0.71	0.74	0.59	0.56	0.15
15	0.06	0.85	0.82	0.62	0.59	0.56	0.15
16	0.06	0.94	0.88	0.65	0.71	0.50	0.12
17	0.09	0.85	0.71	0.68	0.74	0.44	0.09
18	0.09	0.88	0.76	0.71	0.65	0.47	0.12
19	0.15	0.76	0.79	0.85	0.74	0.41	0.12
20	0.12	0.85	0.82	0.76	0.68	0.38	0.12
21	0.15	0.88	0.79	0.85	0.71	0.41	0.12
22	0.15	0.82	0.62	0.82	0.71	0.44	0.12
23	0.18	0.71	0.62	0.79	0.62	0.47	0.09
24	0.21	0.79	0.56	0.82	0.62	0.38	0.12
25	0.29	0.76	0.50	0.74	0.74	0.41	0.06
26	0.35	0.76	0.53	0.76	0.71	0.38	0.03
27	0.38	0.76	0.65	0.79	0.76	0.38	0.03
28	0.44	0.82	0.68	0.79	0.76	0.35	0.06
29	0.47	0.76	0.76	0.76	0.76	0.35	0.03
30	0.59	0.74	0.71	0.65	0.79	0.32	0.03
31	0.0	0.76	0.0	0.65	0.59	0.0	0.03

TABLE G 8: EDMONTON (STATION NUMBERS 2195-2208)-

PROBABILITY OF A WORK DAY ON SANDY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.04	0.71	0.78	0.71	0.84	0.80	0.73
2	0.33	0.73	0.87	0.80	0.80	0.89	0.76
3	0.31	0.84	0.82	0.71	0.73	0.87	0.67
4	0.40	0.71	0.84	0.76	0.73	0.73	0.69
5	0.42	0.80	0.87	0.71	0.73	0.84	0.62
6	0.40	0.80	0.93	0.73	0.76	0.76	0.76
7	0.40	0.80	0.82	0.76	0.69	0.76	0.73
8	0.47	0.80	0.78	0.69	0.82	0.89	0.69
9	0.49	0.89	0.91	0.82	0.80	0.89	0.76
10	0.49	0.84	0.89	0.78	0.76	0.82	0.71
11	0.67	0.91	0.84	0.82	0.78	0.76	0.73
12	0.76	0.93	0.80	0.87	0.73	0.69	0.78
13	0.71	0.96	0.73	0.78	0.82	0.73	0.76
14	0.60	0.93	0.82	0.78	0.78	0.73	0.67
15	0.58	0.96	0.80	0.84	0.69	0.71	0.62
16	0.64	0.87	0.76	0.71	0.80	0.78	0.71
17	0.67	0.73	0.78	0.60	0.82	0.67	0.73
18	0.67	0.87	0.71	0.87	0.76	0.67	0.69
19	0.73	0.93	0.87	0.80	0.89	0.69	0.73
20	0.60	0.89	0.82	0.80	0.84	0.69	0.73
21	0.71	0.89	0.93	0.82	0.84	0.60	0.64
22	0.64	0.76	0.73	0.89	0.78	0.73	0.64
23	0.62	0.84	0.67	0.69	0.73	0.76	0.62
24	0.71	0.91	0.69	0.78	0.82	0.67	0.64
25	0.71	0.80	0.60	0.78	0.76	0.60	0.62
26	0.73	0.87	0.73	0.84	0.73	0.67	0.64
27	0.76	0.82	0.84	0.78	0.69	0.69	0.56
28	0.82	0.84	0.87	0.78	0.71	0.69	0.51
29	0.87	0.93	0.73	0.73	0.73	0.67	0.51
30	0.73	0.82	0.69	0.71	0.71	0.73	0.51
31	0.0	0.82	0.0	0.82	0.82	0.0	0.42

TABLE G 9: VERMILION (STATION NUMBER 6800)-

PROBABILITY OF A WORK DAY ON SANDY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.05	0.75	0.90	0.85	0.80	0.65	0.70
2	0.25	0.75	0.95	0.85	0.80	0.85	0.75
3	0.30	0.75	0.95	0.85	0.85	0.75	0.75
4	0.45	0.75	0.85	0.90	0.70	0.85	0.60
5	0.50	0.85	0.75	0.75	0.85	0.95	0.65
6	0.30	0.85	0.85	0.80	0.85	1.00	0.75
7	0.45	0.85	0.95	0.85	1.00	0.85	0.75
8	0.40	0.95	0.90	0.95	0.80	0.80	0.75
9	0.45	1.00	0.85	0.90	0.80	0.85	0.80
10	0.30	0.95	0.75	0.85	0.60	0.90	0.70
11	0.55	0.95	0.85	0.75	0.75	0.85	0.85
12	0.60	0.85	0.80	0.90	0.80	0.65	0.80
13	0.70	0.90	0.75	0.90	0.80	0.80	0.90
14	0.70	0.75	0.95	0.50	1.00	0.85	0.80
15	0.65	0.95	0.70	0.75	0.85	0.70	0.75
16	0.70	0.85	0.85	0.80	0.70	0.65	0.75
17	0.55	0.85	0.75	0.70	0.80	0.70	0.85
18	0.65	1.00	0.80	0.85	0.80	0.75	0.90
19	0.55	0.95	0.95	0.80	0.85	0.85	0.90
20	0.40	0.85	0.85	0.85	0.80	0.70	0.80
21	0.55	0.85	0.75	0.85	0.90	0.75	0.70
22	0.70	0.85	0.65	0.95	0.75	0.70	0.65
23	0.75	1.00	0.80	0.90	0.90	0.75	0.75
24	0.60	0.80	0.80	0.90	0.70	0.70	0.70
25	0.70	0.90	0.75	0.60	0.65	0.80	0.65
26	0.60	0.85	0.70	0.90	0.60	0.80	0.65
27	0.60	0.95	0.80	0.60	0.70	0.65	0.70
28	0.75	0.95	0.90	0.85	0.70	0.70	0.75
29	0.70	0.90	0.70	0.80	0.85	0.55	0.70
30	0.70	0.80	0.70	0.75	0.75	0.65	0.60
31	0.0	0.85	0.0	0.90	0.80	0.0	0.55

TABLE G10: CALGARY (STATION NUMBERS 1080-1100)-

PROBABILITY OF A WORK DAY ON SANDY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.09	0.70	0.76	0.67	0.76	0.80	0.80
2	0.39	0.74	0.78	0.80	0.87	0.83	0.87
3	0.39	0.83	0.72	0.76	0.83	0.93	0.78
4	0.50	0.78	0.78	0.85	0.85	0.87	0.80
5	0.46	0.78	0.74	0.76	0.76	0.80	0.72
6	0.43	0.85	0.74	0.78	0.85	0.87	0.76
7	0.48	0.72	0.76	0.83	0.87	0.80	0.78
8	0.59	0.74	0.80	0.78	0.87	0.76	0.74
9	0.52	0.87	0.76	0.93	0.87	0.83	0.70
10	0.57	0.83	0.78	0.91	0.89	0.78	0.74
11	0.70	0.83	0.76	0.87	0.78	0.78	0.72
12	0.72	0.91	0.83	0.87	0.83	0.72	0.80
13	0.72	0.74	0.83	0.85	0.80	0.78	0.80
14	0.57	0.78	0.80	0.85	0.85	0.80	0.80
15	0.61	0.89	0.67	0.93	0.83	0.85	0.85
16	0.61	0.80	0.80	0.80	0.87	0.80	0.80
17	0.65	0.85	0.76	0.85	0.89	0.76	0.76
18	0.65	0.87	0.78	0.89	0.85	0.65	0.74
19	0.78	0.89	0.78	0.80	0.80	0.72	0.76
20	0.61	0.80	0.74	0.83	0.67	0.67	0.74
21	0.70	0.87	0.78	0.91	0.87	0.70	0.70
22	0.54	0.83	0.67	0.89	0.83	0.76	0.74
23	0.61	0.85	0.76	0.89	0.80	0.70	0.72
24	0.65	0.80	0.72	0.76	0.76	0.72	0.76
25	0.63	0.83	0.74	0.87	0.85	0.76	0.70
26	0.72	0.80	0.65	0.96	0.80	0.76	0.72
27	0.61	0.93	0.72	0.91	0.80	0.80	0.59
28	0.65	0.89	0.67	0.72	0.87	0.80	0.57
29	0.74	0.83	0.74	0.85	0.80	0.76	0.63
30	0.67	0.76	0.87	0.89	0.83	0.78	0.63
31	0.0	0.76	0.0	0.80	0.91	0.0	0.61

TABLE G11: LETHBRIDGE (STATION NUMBERS 3880-3890)-

PROBABILITY OF A WORK DAY ON SANDY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.20	0.80	0.78	0.84	0.91	0.84	0.84
2	0.40	0.78	0.82	0.87	0.96	0.82	0.92
3	0.49	0.87	0.78	0.87	0.91	0.87	0.78
4	0.51	0.76	0.76	0.91	0.93	0.96	0.76
5	0.58	0.87	0.82	0.87	0.93	0.78	0.71
6	0.53	0.87	0.78	0.93	0.91	0.89	0.78
7	0.51	0.82	0.82	0.80	0.89	0.82	0.84
8	0.56	0.84	0.82	0.82	0.91	0.80	0.76
9	0.56	0.82	0.76	0.87	0.89	0.89	0.82
10	0.67	0.80	0.76	0.87	0.84	0.73	0.82
11	0.69	0.89	0.78	0.84	0.91	0.82	0.80
12	0.76	0.84	0.73	0.93	0.91	0.91	0.78
13	0.71	0.76	0.82	0.96	0.93	0.89	0.84
14	0.69	0.82	0.78	0.82	0.93	0.91	0.82
15	0.71	0.82	0.82	0.91	0.87	0.82	0.87
16	0.69	0.84	0.78	0.80	0.91	0.80	0.84
17	0.71	0.87	0.84	0.89	0.96	0.76	0.80
18	0.69	0.82	0.84	0.98	0.91	0.71	0.78
19	0.80	0.82	0.82	0.87	0.89	0.76	0.76
20	0.69	0.82	0.73	0.89	0.87	0.71	0.76
21	0.73	0.80	0.73	0.96	0.93	0.73	0.73
22	0.64	0.78	0.69	0.93	0.89	0.78	0.73
23	0.62	0.80	0.82	0.93	0.84	0.73	0.73
24	0.62	0.84	0.82	0.87	0.84	0.78	0.84
25	0.64	0.84	0.87	0.87	0.82	0.78	0.82
26	0.76	0.87	0.73	0.93	0.87	0.76	0.78
27	0.60	0.89	0.82	0.89	0.87	0.76	0.71
28	0.71	0.89	0.87	0.84	0.89	0.80	0.69
29	0.78	0.82	0.87	0.93	0.87	0.82	0.69
30	0.73	0.89	0.89	0.93	0.78	0.84	0.76
31	0.0	0.84	0.0	0.93	0.89	0.0	0.69

TABLE G12: MEDICINE HAT (STATION NUMBER 4480)-

PROBABILITY OF A WORK DAY ON SANDY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.20	0.89	0.78	0.82	0.91	0.91	0.84
2	0.42	0.80	0.96	0.91	0.98	0.87	0.87
3	0.56	0.93	0.78	0.91	0.96	0.89	0.80
4	0.58	0.89	0.80	0.89	0.93	0.84	0.87
5	0.64	0.89	0.84	0.89	0.91	0.91	0.87
6	0.51	0.87	0.91	0.87	0.93	0.89	0.84
7	0.53	0.82	0.87	0.89	0.89	0.87	0.91
8	0.67	0.89	0.91	0.93	0.84	0.73	0.84
9	0.64	0.96	0.82	0.91	0.87	0.91	0.92
10	0.58	0.82	0.82	0.93	0.84	0.82	0.80
11	0.73	0.96	0.89	0.89	0.89	0.82	0.80
12	0.80	0.91	0.87	0.91	0.91	0.89	0.80
13	0.87	0.89	0.82	0.89	0.91	0.84	0.82
14	0.69	0.92	0.80	0.89	0.89	0.91	0.87
15	0.78	0.89	0.78	0.93	0.87	0.84	0.89
16	0.80	0.91	0.80	0.84	0.91	0.82	0.84
17	0.78	0.87	0.84	0.87	0.96	0.92	0.84
18	0.87	0.87	0.89	0.89	0.93	0.82	0.84
19	0.87	0.89	0.82	0.89	0.89	0.80	0.82
20	0.73	0.84	0.89	0.82	0.87	0.78	0.82
21	0.78	0.84	0.82	0.91	0.87	0.78	0.71
22	0.69	0.84	0.80	0.98	0.96	0.78	0.69
23	0.71	0.82	0.82	0.96	0.89	0.76	0.71
24	0.80	0.91	0.89	0.93	0.71	0.78	0.71
25	0.78	0.91	0.82	0.82	0.93	0.76	0.71
26	0.76	0.89	0.78	0.92	0.91	0.80	0.76
27	0.76	0.91	0.87	0.91	0.87	0.76	0.71
28	0.92	0.93	0.80	0.91	0.91	0.80	0.69
29	0.80	0.91	0.82	0.93	0.91	0.82	0.64
30	0.80	0.87	0.82	0.98	0.94	0.84	0.62
31	0.0	0.89	0.0	0.91	0.89	0.0	0.58

TABLE G13: BEAVERLODGE (STATION NUMBER 560)-

PROBABILITY OF A WORK DAY ON SANDY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.0	0.71	0.96	0.91	0.89	0.69	0.53
2	0.13	0.80	0.96	0.84	0.82	0.71	0.58
3	0.22	0.80	0.87	0.89	0.84	0.67	0.60
4	0.29	0.89	0.87	0.87	0.73	0.67	0.60
5	0.33	0.84	0.87	0.76	0.80	0.76	0.60
6	0.31	0.87	0.96	0.80	0.78	0.71	0.62
7	0.36	0.84	0.84	0.76	0.84	0.73	0.60
8	0.38	0.80	0.96	0.73	0.91	0.78	0.62
9	0.47	0.87	0.84	0.82	0.87	0.80	0.67
10	0.47	0.87	0.80	0.82	0.82	0.76	0.58
11	0.64	0.93	0.82	0.84	0.82	0.78	0.56
12	0.58	0.87	0.82	0.84	0.76	0.73	0.49
13	0.49	0.80	0.87	0.82	0.76	0.76	0.56
14	0.56	0.84	0.82	0.78	0.76	0.67	0.53
15	0.60	0.98	0.84	0.73	0.71	0.62	0.47
16	0.64	0.89	0.82	0.73	0.80	0.51	0.56
17	0.62	0.91	0.84	0.84	0.84	0.51	0.51
18	0.69	0.89	0.76	0.80	0.84	0.56	0.53
19	0.58	0.84	0.73	0.93	0.87	0.64	0.49
20	0.53	0.89	0.89	0.84	0.78	0.60	0.47
21	0.60	0.91	0.82	0.91	0.78	0.64	0.44
22	0.73	0.87	0.76	0.91	0.80	0.67	0.42
23	0.67	0.84	0.78	0.80	0.71	0.69	0.51
24	0.67	0.84	0.91	0.87	0.80	0.58	0.49
25	0.80	0.84	0.71	0.69	0.73	0.60	0.40
26	0.76	0.80	0.71	0.71	0.76	0.60	0.33
27	0.78	0.84	0.73	0.76	0.82	0.60	0.36
28	0.78	0.84	0.84	0.76	0.82	0.56	0.36
29	0.73	0.80	0.82	0.87	0.73	0.53	0.31
30	0.73	0.89	0.82	0.80	0.73	0.51	0.31
31	0.0	0.87	0.0	0.80	0.71	0.0	0.27

TABLE G14: FAIRVIEW (STATION NUMBER 2520)-

PROBABILITY OF A WORK DAY ON SANDY SOILS

DAY	APR	MAY	JUNE	JULY	AUG	SEPT	OCT
1	0.03	0.74	0.88	0.79	0.88	0.59	0.53
2	0.15	0.74	0.91	0.76	0.91	0.56	0.53
3	0.29	0.79	0.97	0.82	0.76	0.76	0.50
4	0.26	0.88	0.91	0.76	0.76	0.56	0.59
5	0.18	0.85	0.97	0.71	0.82	0.74	0.74
6	0.29	0.82	0.82	0.91	0.79	0.79	0.65
7	0.35	0.85	0.85	0.85	0.82	0.85	0.68
8	0.28	0.82	0.94	0.71	0.85	0.79	0.56
9	0.35	0.85	0.88	0.79	0.91	0.91	0.62
10	0.38	0.85	0.85	0.79	0.82	0.82	0.56
11	0.53	0.85	0.91	0.91	0.74	0.71	0.59
12	0.62	0.91	0.76	0.91	0.76	0.74	0.47
13	0.50	0.85	0.82	0.85	0.71	0.74	0.44
14	0.47	0.91	0.88	0.74	0.65	0.68	0.41
15	0.53	0.94	0.94	0.71	0.68	0.68	0.50
16	0.59	0.94	0.91	0.71	0.85	0.59	0.47
17	0.65	0.88	0.71	0.88	0.79	0.56	0.41
18	0.71	0.91	0.85	0.82	0.74	0.65	0.44
19	0.53	0.85	0.85	0.88	0.88	0.62	0.44
20	0.56	0.94	0.82	0.79	0.79	0.59	0.38
21	0.56	0.94	0.82	0.85	0.82	0.68	0.35
22	0.68	0.85	0.68	0.88	0.79	0.71	0.35
23	0.71	0.76	0.76	0.82	0.68	0.74	0.32
24	0.59	0.85	0.59	0.85	0.65	0.68	0.38
25	0.76	0.82	0.59	0.74	0.85	0.62	0.26
26	0.82	0.85	0.65	0.82	0.85	0.56	0.26
27	0.74	0.85	0.76	0.82	0.85	0.62	0.24
28	0.76	0.91	0.76	0.82	0.82	0.53	0.26
29	0.71	0.85	0.82	0.76	0.82	0.50	0.21
30	0.76	0.82	0.71	0.74	0.91	0.50	0.18
31	0.0	0.88	0.0	0.79	0.71	0.0	0.15